ON MODELLING THE ENGINEERING DESIGN PROCESS,

WITH SPECIAL REFERENCE

TO THE DESIGN OF MATERIALS HANDLING SYSTEMS

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by

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E R R A T A

Page 3, paragraph 4, second sentence should read:

People are essential for the creative processes, but the productivity of people in performing evaluative processes may be improved wherever evaluation can be expressed as a formalised logical process.

Page 45, second paragraph, first sentence, should read:

This model was chosen because it provides a rigorously defined system of concepts to explain human behaviour.

Page 46, second sentence, should read:

A purposive situation is characterised by four components.

Now, it is sheer nonsense to expect that any human being has yet been able to attain such insight into the problems of society that he can really identify *the* central problems and determine how they should be solved. The systems in which we live are far too complicated as yet for our intellectual powers and technology to understand. Given the limited scope of our capability to solve the social problems we face, we have every right to question whether any approach - systems approach, humanist approach, artist's approach, engineering approach, religious approach, psychoanalytic approach - is *the* correct approach to the understanding of our society. But a great deal can be learned by allowing a clear statement of an approach to be made in order that its opponents may therefore state their opposition in as cogent a fashion as possible.

C. West Churchman.

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ABSTRACT

The task of increasing the efficiency whereby industry converts resources to products has occupied the minds of technical researchers since time immemorial. Man's quest for optimal production systems has traditionally involved expenditure of human effort to design and develop new and more efficient production machines, improved materials, production processes, and organisations. More recently, with the advent of high speed digital computers, man's effort has expanded to include research into the use of computers to aid and improve the efforts of the designer. Aiding the design process as it is applied to one particular component of an industrial organisation, namely the material handling activity, is the objective of this study.

Implicit in this objective is the need to examine four interrelated topics. Firstly, it is necessary to identify the components which are fundamental to any handling situation, as these will influence the designer's choice during the design process. Secondly, the difficulties of designing systems in general, and handling systems in particular are examined. Thirdly, since technical people have always maintained a unique role in the design process, it is logical to identify this role by examining the mental attributes which enable them to perform complex design tasks with considerable success. Fourthly and finally, the characteristics of design problems in which computers have produced feasible solutions are identified by examining four case studies.

The information obtained from these topics, combined with practical principles and design rules from current design literature, provide the bases for development of a logical design procedure. This procedure is presented together with an example of its application to an actual handling system design problem.

CONTENTS

CHAPTER ONE

INTRODUCTION

The objective of this study is to investigate the application of digital computers to aid the design of material handling systems. Although a considerable amount of literature has been written on the practice of designing handling systems, none provides a logical procedure which can be performed partially or wholely by computer. Existing schemes (e.g. ref's 1 and 2) require a human designer to develop his strategy anew for each problem, thus a logical design procedure will be sought wherein the factors which influence the designer's choice merge with the abilities of a digital computer.

The conjunction of two factors provides the impetus for this study; (1) the need to increase the contribution of manufacturing industry to the New Zealand economy through improved technology, and (2) the philosophy held by the research group at the University of Canterbury that digital computers can increase the productivity of technically qualified staff.

New Zealand's economy is largely dependent upon revenue earned from exports. Traditionally, the majority of these exports have been pastoral products, particularly wool, mutton, beef, butter, and cheese, which have recently been joined by wood pulp and paper products as principal earners, together providing about three-quarters of our total export income. These products are luxuries to most of the world's consumers and are subjected to widely varying prices, which combined with the proportion of their contribution to the economy creates large fluctuations in the wealth of this nation. (3). Additionally technological advances in consumer countries have adversely affected the competitive position of these products. Wool, one of the largest earners, has been seriously challenged by synthetic fibres such as nylon in the manufacture of carpets and clothing. Artificial flavouring in margarine has created a strong competitor for butter.

These and other factors have placed renewed emphasis upon the need for an increased production from manufacturing industries. (4). In the short term increased production would reduce the need to import those products which can be made locally, while in the longer term it would expand the range of products available for export and thus act to stabilise the economy.

Goods manufactured for export must compete in an international market-place in both quality and cost. The strongest competition comes from those nations who can employ low cost labour and/or who possess modern technologies: New Zealand's labour is not low cost and there is an ever-present need for manufacturers to buy and use the latest technology. This places the manufacturer in a problem situation where he is dissatisfied with his ability to compete in foreign markets and is doubtful about what action he can take to improve his position. Although he perceives a need to use new technologies, in many cases he lacks the technical and social knowledge necessary to make a competent choice.

Two examples of recent technological advances in handling equipment offer considerable potential to New Zealand's manufacturers; these are multi-programmable industrial robots and feller-bunchers. Industrial robots will find their initial application as handling devices loading and unloading existing production machines, while feller-bunchers are being introduced into exotic forests to harvest trees for the manufacture of pulp and paper products. Because of the novelty of these machines, manufacturers do not possess, nor can they easily obtain, design experience of the systems which incorporate them. This coupled with the high capital cost and technical complexity of such systems aggravates the manufacturer's problem.

These factors indicate a need for a logically structured design procedure which can be used to assist in the selection of systems of handling equipment.

The philosophy of our research is to study areas of potential improvement in the productivity of technically qualified manpower; rather than in the productivity of manual workers. Designing is one important activity in industry carried out by technical manpower. To produce a design requires a procedure and adequate information; therefore, to increase the productivity of a designer it is necessary to improve his design procedure and/or the information he has available to him.

The design process can be regarded as an information processing activity which can be divided into creative and evaluative processes. People are essential for the creative processes but the productivity of people in performing EVALUATIVE ~~routine logical~~ processes may be improved wherever ~~greatly by~~ evaluation can be expressed and formalised logical processes ~~proper design of those processes~~.

This thesis will concentrate upon improving the design procedure available to material handling systems designers.

As a result of the preceding discussion the contents of this thesis will be presented in the following manner.

Initially, in Chapter Two there is a discussion on the historical development of New Zealand's manufacturing industry, and its role in the national economy in the past, the present, and the future. Industry's future role is discussed in terms of the economic contribution required, and the policies towards technology that are needed to realise this contribution. The philosophy held by this research group is discussed in greater detail.

Next, there is a group of six chapters headed "Part One: Definition of the Problem". This part presents four topics which are fundamental to the development of a logical design procedure. Chapters three and eight identify the physical and organisational variables which influence the designer's choice of solution. Normally this solution will comprise one or more items of handling equipment such as conveyors, trolleys, and people, which interact to form a handling system. The interactiveness of the components of a system produce particular difficulties for a designer, which are examined in Chapter four. Chapter five examines mental processes, such as thought and intuition, which enable human designers to create novel solutions to design problems. Chapters six and seven analyse four case studies in which computers had been used to produce feasible designs. In each case they produced designs more economically than could human designers. The characteristics of these problems which made computer solutions possible were identified together with the factors which influence their complexity.

The second group of chapters headed "Part Two: A Logical Procedure for Designing Handling Systems", uses the information developed in part one, together with design principles and rules taken from current design literature, to develop a logical design procedure. This procedure is demonstrated by application to an actual handling system design task.

A general conclusion compares the findings of this project with the stated objectives, and makes recommendations on the application of the design procedure to particular classes of handling system design problems.

The structure of this study is illustrated in Figure 1.1.

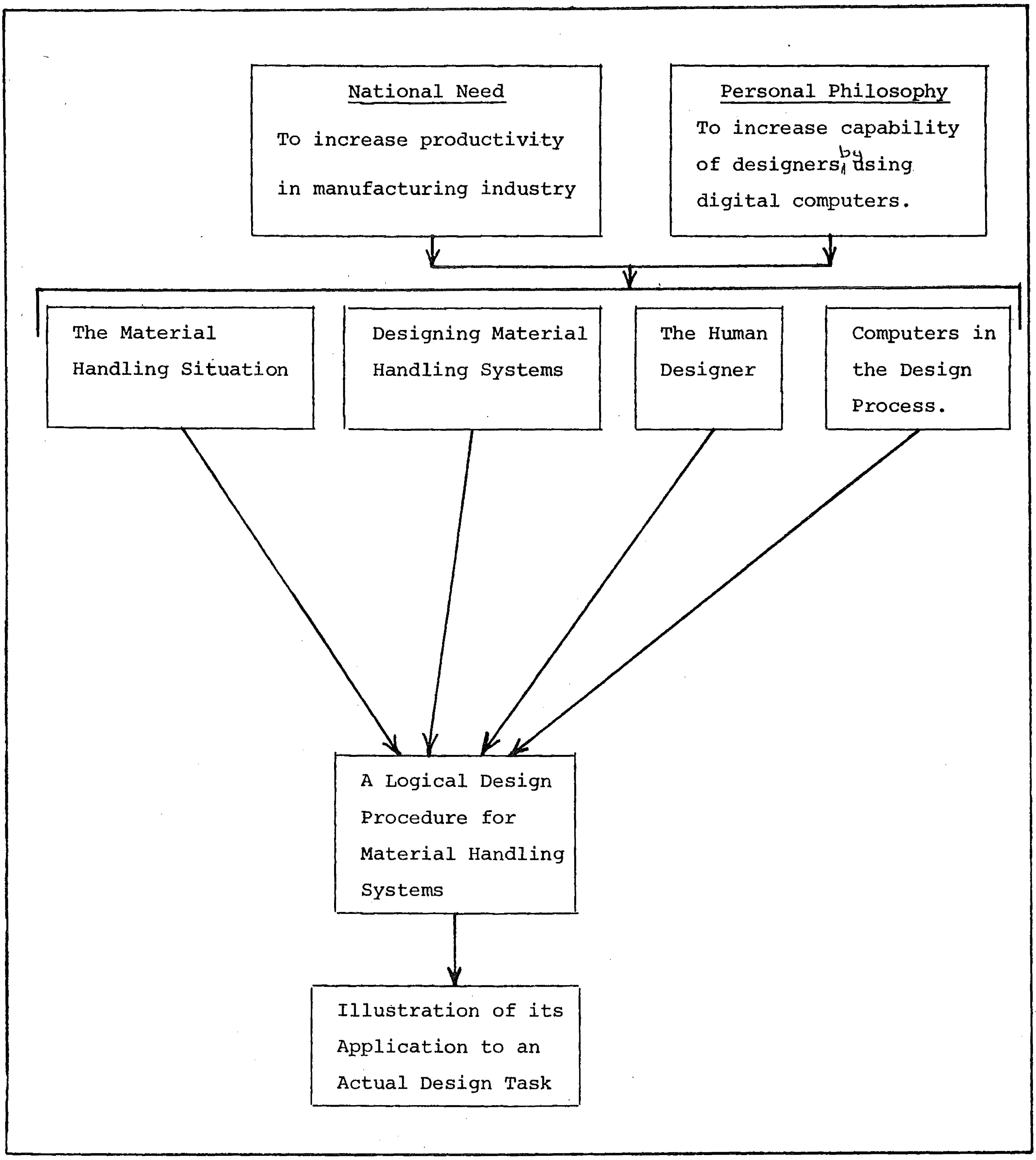


FIGURE 1.1 THE GENERAL STRUCTURE OF THIS STUDY

CHAPTER TWO

THE LANGUAGE OF JUSTIFICATION

2.1 Background

It is impossible to justify any study in the language of that study. If a handling system design problem is conceived as a network in which the nodes represent variables and constants describing it, and lines connecting these nodes represent relationships between them, then there is nothing within this network capable of discussing the validity of the structure, the purpose for generating it, or the purpose for providing a solution to the problem portrayed by it. What is required is a language of a logically higher order than that describing the problem; that is a metalanguage. This metalanguage needs to discuss the structure of New Zealand's manufacturing industry, both in the past, the present, and the future; economics at a national level, the impact of technology on manufacturing industry, on productivity, and on the people; and finally our philosophy on the methodology of problem solving.

2.2 The Structure of New Zealand's Manufacturing Industry

The beginning is relatively recent by world standards making it necessary to refer back in time only a little over one hundred years to the middle of the nineteenth century. At this time New Zealand was still a very new and sparsely populated colony with the european population scattered along an extended coastline in a number of tiny settlements more closely linked with the outside world than they were with each other. Prior to 1840, europeans and americans had come to New Zealand primarily to exploit resources which promised quick profits without the necessity for permanent settlement. A more positive impulse to prosperity - the first perhaps, other than immigration, to reach this country from the outside world - came when gold was discovered in Victoria shortly after the mid-century. The rise of prices and inadequacy of Australian production of foodstuffs gave New Zealand farmers an opportunity which they did not miss. By the middle of the 1850's thriving exports of foodstuffs had grown up, and vegetables and grain ranked with wool as the three principal exports.

With this background of exploitation of natural resources and the rise in agricultural production it is not surprising that the initial function of the early manufacturing industries was to supply locally the immediate needs of these isolated settlements. These included food, clothing, building materials, and home furnishings, as well as providing shipping with ropes, spars, and general repairs.

New Zealand experienced the stimulus of gold first hand in the early 1860's when alluvial deposits were discovered in Central Otago and later in Westland. The fields were not large by world standards but in relation to the resources of the country at the time they were of major importance. New Zealand experienced her most rapid population growth during this period which in turn placed unprecedented demands on manufactured goods. By 1867 manufacturing establishments included grainmills, breweries, biscuit factories, candle and soap manufacturers, tanneries, woolscours and mills, iron and brass foundries, engineering workshops, a graving dock, rope and cordage makers, sawmills, and ship and boat yards. Enhancement of the country's capital assets which gold bequeathed, real though it was, was not adequate to guard against the possibility of falling incomes for the now much larger population, especially when gold production declined and the price of grain and wool fell in the late 1860's.

The last two decades of the century proved to be a sobering experience for the young nation with substantial declines in export earnings for agricultural production. Tariffs were imposed to protect footwear, clothing, machinery, and metalworking industries. During this period low wages enabled the export of some manufactured products; the first shipment of frozen mutton in 1882 opened the way for growth in the meat-freezing, butter, and cheese industries.

The final four years of the century saw a steady recovery from the depression and a subsequent rise in value of factory production; some of the larger rises occurring in the iron and brass foundries, furniture factories, and flaxmills. After the turn of the century economic conditions continued to favour manufacturing development. Large-scale immigration was resumed and export income rose as a result of the development of refrigeration of farm export products. Growth continued to be concentrated in industries processing farm export products and those supplying the more simple goods, housing materials, repairs, and supplies for farms. In this period electrical, wirework, sheetmetal, and motor vehicle industries began.

Steady increase in production continued until the early twenties when a considerable fall occurred in manufacturing production. Various factors contributed to this fall. There was a major post war boom in 1920 but fluctuation in export prices were reflected in farm increases and in the economy generally, and thus the demand for goods in New Zealand was unstable. Unemployment lowered this demand for consumer goods. Manpower shortages during the First World War had prevented any significant increase in manufacturing. Increases in demand from the rising population or rising national income had to be met by imports.

The world depression of the early thirties caused a fall in purchasing power which in turn caused the farmer to produce more but the impact of the depression on 'non-farm' manufactures meant a heavy reduction in the output of consumer goods, building materials, agricultural and dairy machinery and implements. By 1935 however the volume of factory production had been restored to the 1929 level, but the depression caused little change in the style of manufacturing.

The Second World War and its shortages changed manufacturing patterns and gave great encouragement to industrial development. Engineering and apparel industries which contributed so much to the war effort, made the greatest progress. Assured of a large part of the market some manufacturing industries were able to expand without having first to struggle through a difficult period of competition from established overseas producers. During the war years manufacturing output grew by almost one-third. Except for footwear these industries still imported raw materials so that the trend of development during the pre-war years was continued.

Post war shortages of manufactured goods ended about the beginning of the fifties and the generally good prices for export goods such as wool, continued through the middle fifties, bringing unprecedented prosperity. Despite this there were violent fluctuations in prices and the balance of payments problem remained. Spectacular increases in production came from new developments in the pulp and paper, and the rubber industries. However, as in the past it was the engineering factories which contributed most to the growth of manufacturing after 1950. Expansion was stimulated by increasing mechanisation on farms, the high level of investment in New Zealand, the rising demand for consumer durables, and the increased imports of motor-vehicle components.

More recent developments in manufacturing have again been greatly affected by the old problem of balance of payments. As New Zealand industry develops it lessens reliance on imports but it does not reduce the level of imports. They merely become different in type; if we import fewer garments we import more machinery. Recently renewed emphasis has been placed upon industrialisation; not only to produce internally that which the country could not afford to buy from abroad, but also in an attempt to reduce the vulnerability of relying on a few farm products. Historically, exports of pastoral products averaged over 80% by value of New Zealand's export trade; however, despite the growing importance of manufactured goods, farm produce now contributes about 70% of the total export income.

Greater diversification is seen as at least a partial answer, since it would expand the range of export goods. Development in depth is also needed; a concept entailing the importation of raw materials or partly finished goods, so that goods made in New Zealand for the home market would have the greatest local content and thus enable more goods to be available to the New Zealand market for a given expenditure of foreign exchange. Similarly, the aim with exported products is to manufacture and process the country's own raw materials into products as much as possible before export so the greatest amount of foreign exchange can be earned.

These then are some of the factors which have influenced the development of New Zealand's industry since its beginnings last century. The geographical features of the country as well as the needs of isolated communities influenced the structure of these industries in the earliest days; a structure which still persists today. Small factories continue to be typical of manufacturing in New Zealand with some 51% of factories employing ten or fewer people supplying local markets. By contrast only

2.2% of factories have a staff in excess of 200. The majority of small manufacturing units are involved in the production of transport equipment, machinery, and wood products, while the largest plants are engaged in the manufacture and processing of food and paper.

Although this industrial structure is convenient for local market production, it is at a disadvantage when competing in an international market. Factory size precludes the economies of scale found in mass production. New Zealand is a long way from major markets and transport costs are high; labour rates are comparable with those in more industrialised nations; and finally New Zealand does not possess significant quantities of natural resources such as minerals and energy which are currently in high demand.

The question now posed is which policies should be adopted to improve the competitive position of these manufacturing industries? During 1974 the National Research Advisory Council (4) considered research requirements in the field of technology associated with lack of productivity, an area of concern to industry. A considerable amount of effort was spent analysing how industrial and production technology research could best be stimulated, and what resources would be required. Several areas were outlined which could benefit from this type of research, one of which was the use of computers to assist industrial design problems.

2.3 Technology, Production, and Change

Since the Second World War growth has been a notable feature in the economies of most western nations as well as Communist Russia. Economic growth means the production and supply of a growing volume of goods and services of all kinds. Obviously the adoption of new products and industrial processes have an influence on growth, but it is only quite recently economists began to recognise the importance of technological growth.

Growth in output is traditionally attributed to an increase in factor inputs: capital, labour, and land. Growth in the last century may in part be explained by greater exploitation of land and natural resources, deployment of more capital resources (e.g. machinery and vehicles), and the deployment of a greater volume of human labour.

But output may also grow due to changes in technology. Plain growth of output depends upon many factors including scale of production, size of market, educational system, and social structure, but without the technological changes in production methods which permit more output from a given quantity of resources the recent historic growth of industrial economies could not have occurred.

Technological change is an important factor in productivity growth. The term "labour productivity" is sometimes used to measure output per employee. Possible factors which can contribute to increased productivity include:

(1) People working harder or more efficiently.

(2) Substitution of capital equipment for human labour.

(3) Development of new technologies.

(4) Economies of scale.

In the industrial nations the dominant influences appear to have been technological innovation and economies of scale; however, it is worth examining each of these factors within the context of New Zealand's industry.

The need for people to work harder to increase productivity is incompatible with the philosophy upon which automation and technological change is based. Technology should be aimed at improving the lot of the human being and society rather than demanding an ever increasing work effort. Certainly technological change has been responsible for changing the demand for various types of skills; there arises a demand for more highly educated people, whilst those with little formal education become rapidly less employable. However the need to work harder does not arise, as evidenced by the decline in the hours worked per week. In the United States of America sixty hour work weeks have decreased to thirty seven hours in less than sixty years while during the same period a three-fold increase in production has occurred.

Increasing the efficiency with which people work was the pre-occupation of people like F. W. Taylor and the Gilbreths who pioneered the concepts of work study. These concepts were fundamental to piecework and incentive bonus schemes which provided a financial incentive to workers to increase their production. However there is a physical and mental limitation to an individual's output and work study techniques can only approach these limits. If still greater productivity is required then machines are needed to transcend these human limits.

Replacement of human muscle by machine was the principal theme of the Industrial Revolution and was largely responsible for the increase in productivity achieved during the last 200 years. However the emphasis was upon the replacement of muscle leaving the elements of control to man. Superficially this appears to be a desirable situation but many of the control tasks turned into monitoring tasks - monitoring semi-automatic machines. These are the tasks which have borne the brunt of criticism of technological change and automation. Norbet Wiener saw the current trends in automation as a "Second Industrial Revolution", in which emphasis has shifted from the replacement of human muscle to replacement of human control. Although it embodies all of the results of the "First Industrial Revolution", the second revolution is based upon two fundamental ideas in control: feedback and amplification. These have been reinforced by theoretical treatment of communication which has been detailed and expanded in the science of cybernetics founded by Wiener himself. The conjunction of these circumstances now renders possible the new automatic age.

Given both the theoretical principles of control combined with the technological ability to implement them it would seem that the introduction of new devices and the dates at which they are introduced is largely dependent upon economic matters: matters which can be discussed in monetary terms. But what does this mean in terms of human values? After all we are human beings, production is for consumption and the act of making things should be as far as possible linked with the human being.

The human case can be represented by four groups: the state, management, trade unions, and the individual worker. Sir Leon Bagrit(5) in his fourth lecture said, "Whichever party is in power must understand that the age in which we live is a revolutionary and rapidly changing one. It must be aware of what is happening in the rest of the world, and once there is agreement on the fundamental direction in which we move, our educational system, our export policy, our investment policy, would fall into place in the overall pattern". An awareness by government of technology, change, and its social effects provides the beginning, management and trade unions must also play their part.

Perhaps the greatest changes will occur in management and clerical work rather than with workers on the shop floor. Computers and control mechanisation will demand new skills from management. Managers will be required to use specialist advice to solve complex technical problems while at the same time remaining aware of men's needs and aspirations.

The trade union leader represents the members of his union, that is, he represents their training, their skill, and some of their aspirations; and one of the functions of trade union leadership is to see that mental satisfaction of his membership is preserved in whatever technological change is negotiated. This may involve determining which skills are going to become redundant and to make arrangements for retraining whilst maintaining living standards for those whose skills are no longer required. Not only should trade unions consider factors related to retraining but should be represented in policy decisions on education and training in general.

Currently some trade union leaders are prepared to forego these responsibilities for personal gain and political position.

The individual's right to choose his job will depend largely upon his education. Increased technology and automation means there is an increased need for advanced technologists, that is, more people with university degrees who have completed post graduate courses in industrial technology; more technicians, that is more people with higher education and more advanced training than a skilled tradesman. Above all the demand will be for versatile people.

The fourth factor leading to an increase in productivity assumes there is a market capacity and capital available to establish large scale production plants. The structure of New Zealand's manufacturing industry does not lend itself to large scale production; only a small percentage of companies are able to take advantage of economies of scale.

The manufacturer in New Zealand has a responsibility to the nation to produce goods as cheaply as possible while maintaining an acceptable quality standard. Fulfilling this responsibility requires that technologically advanced plant be used. The greatest need therefore is for an appropriate choice of technology, for manufacturers both large and small to be able to select plant and equipment which best serves their own requirements and is also utilised to benefit the country as a whole.

Implementing the policy to use modern technology requires expertise in design: in systems design. But in the same way as most of our manufacturers cannot justify mass production plant, they cannot justify full-time specialist designers. There is, on a part-time basis, need to provide aid to manufacturers. It is our belief that digital computers, provided with the appropriate software routines and human expertise, can provide a worthwhile contribution. One particular industrial design activity which may benefit from the aid of a computer is material handling systems design.

2.4 Philosophy on Problem Solving

Traditionally science has developed within many separate disciplines each based upon relatively unrelated conceptual systems. This has resulted in the grouping of phenomena into smaller and smaller classes, and in the creation of disciplines specialising in each. As disciplines multiply, each increases in depth and decreases in breadth, collectively they extend scientific knowledge. However such a structure is not conducive to solve complex systems problems. Ackoff and Emery (6) make the following observations in this regard:

"Nature does not come to us in disciplinary form. Phenomena are not physical, chemical, biological, and so on. The disciplines are the ways we study phenomena; they emerge from points of view, not from what is viewed. Hence the disciplinary nature of science is a filing system of knowledge. Its organisation is not to be confused with the organisation of nature itself".

Because of this historical structure for grouping knowledge, the traditional approach to problem solving has been to synthesize the results of disciplinary analysis, rather than by analysing a problem as a whole. E. A. Singer Jr. (7) believed that if we conceive of science as a system of related points of view (instead of as separate disciplines) then in problem solving it is not necessary to reassemble these points of view. Singer showed that an analytical or holistic view must proceed from function to structure, that is, teleologically. By function is meant how an object or event came into being, or what it does or can be used for. Structure refers to the material of which an object is composed and/or its form. Working independently Rosenblueth and Wiener (8) began to see the worth of looking at mechanisms as functional entities. They were concerned with how mechanisms functioned, with mechanisms that served a function, with teleological mechanisms. They found it more useful to proceed conceptually from functionally conceived wholes to structurally conceived parts rather than conversely. Prior to the work of Rosenblueth and Wiener designers tended to develop their understanding of the functioning of a whole system from the structure of its parts and the structural relations between them. Since then designers have tended to develop their conception of the parts by decomposing their conception of the whole. This approach has come to be known as "the systems approach". (Churchman (9)).

The traditional approach is prevalent in the literature describing material handling systems design. References such as Koshkin (10) and Immer (2) are devoted to describing various items of handling equipment in common usage such as conveyors, cranes, and trucks together with the activities to which they are normally assigned. Thus design procedure begins with the designer's knowledge of equipment and its applications, and proceeds toward a solution by selecting equipment from memory. He may supplement his memory if it is inadequate by referring to design texts and/or other designers. This approach is usually subjective. Little effort is made to begin by identifying the essential functions the handling system must provide, the actions required to perform these functions, and the items of handling equipment necessary to produce these actions. A move towards a teleological approach is beginning to appear in the contemporary literature on handling system design, for example Apple (1) and Sutton et al (11).

A teleological approach to problem solving may be subjective or objective. In a subjective teleology properties necessary to describe the problem are identified and defined on a subjective basis, that is depending upon a person's feeling or untested belief. This approach is unlikely to produce optimal or even good solutions consistently from one person to the next. An objective approach demands that definitions be provided as standards to describe the problem situation on a measurable basis. Objective definitions ensure that the resulting solution to a problem is independent of the person providing that solution.

Ackoff (12) identifies two types of scientific definition; conceptual definitions, and operational definitions. Conceptual definitions relate the concept being defined to one or more related concepts.

For example in the context of this study a conceptual definition must be provided to relate the concept of a material handling system to the concepts of handling equipment and the material to be handled. Such a definition tells the reader what to think about in relation to the concept being defined. Conceptual definitions do not however directly relate concepts to experience or experiment. Operational definitions perform this role. They comprise an explicit statement of the activities performed by the concept together with the conditions under which they are performed. For example the concept of an industrial material handling system can be defined operationally in terms of the changes it produces in position and orientation of a specified class of objects. The conditions under which changes occur such as those existing in a production or processing environment must be identified.

An operational definition of a concept cannot be separated from the purposes of the definer, or from the way the concept has been traditionally used. Thus an operational definition of a material handling system must capture the objective of this study, that is to identify a procedure capable of designing the system, as well as the traditional and current usage of the term.

Within the context of a material handling situation the design problem is one of selecting a set of handling equipment capable of performing the transfers desired. Therefore an operational definition of a handling situation will involve identifying objects, events, and properties of these.

Objects such as items of material, items of handling equipment, manufacturing equipment, and so on, need to be defined in terms of the essential properties of each, that is those properties which are both necessary and sufficient for differentiating the class of objects of interest from all other classes. Selection of these properties is determined by the role of the object in the handling situation. For example the geometrical properties of a machine tool will influence the shape of the path travelled when loading material in and out, while properties related to machining processes for example are unlikely to be relevant.

An event is something which happens to one or more objects. That which happens can always be described in terms of a change in properties. For example a material transfer can be thought of as an event in which the properties of position and orientation of an item of material are changed.

This scientific approach to examining problem situations is summarised in Figure 2.1.

In view of our philosophy to provide a rigorous set of definitions as a basis for generating a solution to a problem, chapter three will begin with a conceptual definition of a handling situation followed by operational definitions of each of its component concepts. The objective which influences these definitions is the objective of this study and as such the concepts of design and the role of computers in the design process will be included. The precise nature of these influences is of course identified in the other chapters comprising part one.

Problem Situation

↓

Teleological approach to its solution

This approach involves:

(1) Identification of the essential functions required of a solution.

(2) Identification of the actions necessary to perform these functions.

(3) Identification of the structures capable of performing these actions.

↓

Provision of adequate definitions

These definitions may be:

(1) Conceptual definitions.

(2) Operational definitions.

↓

Definitions include descriptions of objects and events

Objects and events are described in terms of their essential properties which may be:

(1) Structural

(2) Functional

FIGURE 2.1 SUMMARY OF A SCIENTIFIC APPROACH TO PROBLEM SOLVING

PART ONE

Definition of the Problem

INTRODUCTION TO PART ONE

Part One comprises a group of six chapters which identify and examine four topics central to the objective of this thesis. These are; (1) material handling, (2) design as an activity, and in particular systems design, (3) the mental attributes which enable people to produce designs and, (4) characteristics of design problems which have been solved by digital computer.

Chapter Three examines material handling activities identifying and defining the essential components of a handling situation, and the physical interaction between them.

Chapter Four examines design as an activity identifying its characteristics; in particular special difficulties encountered in designing systems.

Human designers appear to possess unique abilities to solve design problems. These are examined in Chapter Five.

Four case studies in which computers solve design problems are examined in Chapter Six, identifying their characteristics which enable computers to provide a solution.

Chapter Seven provides an analysis of these characteristics examining the effect of a number of properties necessary to describe a design problem, their interrelationships within the development of a design process, and the solution.

Finally, Chapter Eight examines one component in the environment of the handling system, namely, the organisation or socio-technical system of which the handling system is a part. The environment's influences upon the handling system and hence the designer are identified.

CHAPTER THREE

DEFINITIONS OF CONCEPTS RELATED TO MATERIAL HANDLING

3.1 Introduction

Material handling as an activity is intuitively understood by most people. If asked to explain the purpose of this activity in an industrial context, most would say it is to change the position of a quantity of material in space. They may add that handling often serves other manufacturing activities, and the positional changes are usually performed over displacements measured in metres rather than in millimetres or kilometres, which distinguish handling from assembly activities involving displacements of a few millimetres, or transporting activities involving displacements over kilometres. Whatever their concept of material handling their explanation will be subjective and they may or may not capture the essential properties which distinguish handling from other industrial activities. Furthermore if asked to describe a handling system the same individuals would probably enumerate items of handling equipment with which they are familiar, such as conveyors, cranes, and so on. Such a description is subjective, varying from individual to individual.

In view of the philosophy on problem solving expressed in the previous chapter, these subjective explanations and descriptions are inadequate. Our objective is to formalise the procedure for designing handling systems therefore it is imperative that a clear and unambiguous understanding of material handling and related concepts be provided.

Current literature does not contain significant information on this subject, therefore developing definitions of material handling activities and related concepts are covered in this chapter.

These definitions are based upon rigorous definitions of structure and function of systems developed in chapter two of Ackoff and Emery (6) and chapters one and five of Ackoff (12).

3.2 The Material Handling Situation

Within an industrial organisation three distinct classes of activites can be identified. Activities associated with managing people and materials, with changing and producing objects, and with transferring people and objects.

Managing activities are essentially controlling and regulating activities. That is managers identify goals, objectives, and ideals, and allocate resources to achieve them.

Production and processing activities may be thought of as actions which produce a change in;

(1) geometrical form of the material or object, and/or

(2) physical properties of the material or object.

Handling activities may be thought of as actions which produce a change in;

(1) location of the material or object in space and time, and/or

(2) orientation of the material or object in space and time.

Therefore a handling activity can be defined as follows:

A Handling Activity: a sequence of actions which produce a change in location and/or orientation of an object or quantity of material in space and time. Individual handling activities are separated in time by processing or storing activities. Storing activities are in a sense the opposite of handling activities in that they prevent changes in location or orientation of an object or material. The need to provide storage arises from a difference in the time between the end of one handling activity and the start of the next, and also from a difference in the rate of material transfer from one handling activity to the next.

Two distinct components of a handling activity are identified from this definition; (1) the material or object being handled, and (2) the path along which it is handled. Figure 3.1 provides a simple illustration of these components.

Logically there must be a class of objects capable of producing this sequence of actions (the handling equipment), and an environment within which these actions are produced, (a manufacturing workshop for example). A handling situation can be defined conceptually in terms of four basic components.

Four components are necessary and sufficient to fully describe a handling situation; (1) a quantity of material or object to be handled, (2) a transfer path, (3) handling equipment, and (4) an environment. Figure 3.2 illustrates the handling situation and its components. Each of these components are defined separately.

(1) The Material: a set of objects that have one or more structural properties in common. In this sense objects are not narrowly conceived as discrete solids but also includes quantities of liquid or gas.

In a handling situation it is usual to classify material into bulk solids, discrete solids, liquids and gases. For each of these classes general subclasses of structural properties can be identified and defined. These include geometric, kinematic, mechanical, and physical properties such as chemical, electrical, magnetic, and thermal properties. These are properties of material which may be defined independently of its

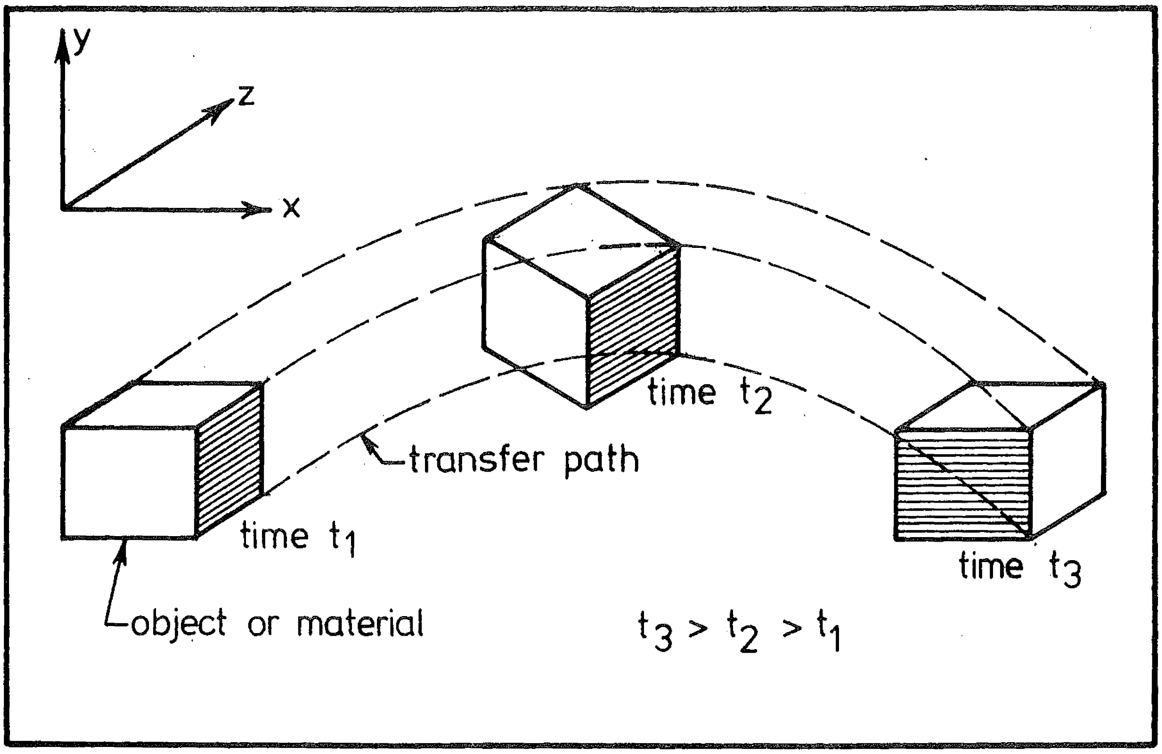


FIG. 3·1. THE COMPONENTS OF A HANDLING ACTIVITY

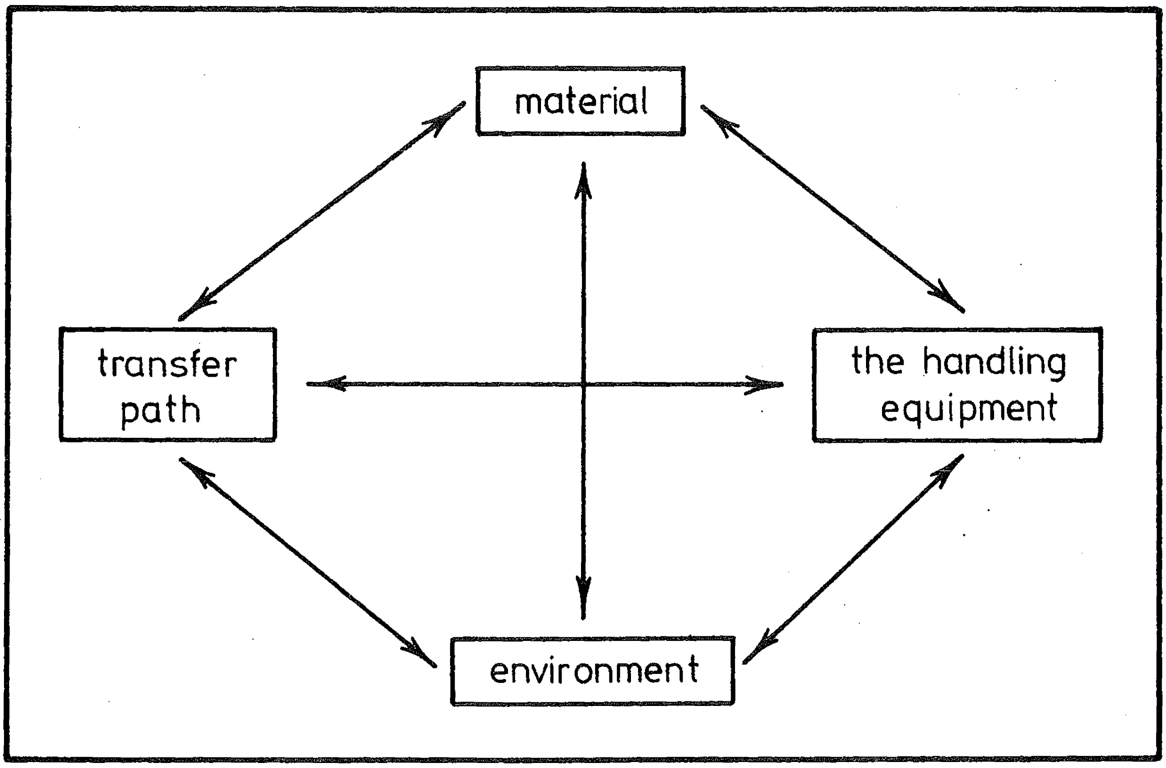


FIG. 3·2 THE COMPONENTS OF THE HANDLING SITUATION position in space. Although all materials possess properties from each of these classes, only a small subset will be of interest in any particular handling situation. Apparently some criteria are necessary to determine whether to include or exclude properties from the material description in a handling situation. The difficulty of providing such criteria is examined in detail in chapter five.

(2) The Transfer Path: a volume swept out in space by the material during its change in position and/or orientation, which can be described geometrically.

The transfer path may vary in shape with time, depending upon terminal characteristics and the containment environment. For example the transfer path may pass between:

(a) Two fixed points, such as fixtures mounted on two adjacent machine tools.

(b) A fixed point and an area, such as from a machine tool to an in-process store.

(c) An area and a fixed point, such as from a store to an assembly station.

(d) Two areas, such as from one store to another.

(3) Handling Equipment: an object or objects which can produce a handling activity.

It is convenient to identify five functional components of an item of handling equipment:

(1) A containment or grasping component.

(2) The structure supporting the containment component.

(3) The prime mover or power generation component.

(4) A power transmission component.

(5) A control component.

For any particular item of handling equipment these components are defined by envelopes of their essential structural properties. For example the payload for an industrial robot may vary from zero to thirty kilograms while the power required to transfer these loads may vary between two and eight kilowatts. These limiting values are independent of any handling situation.

(4) The Environment: A set of objects and/or individuals and their relevant properties which are not part of a handling activity or the handling equipment, but a change in any one of which can cause or produce a change in the handling activity or equipment.

The components of the environment can be divided into two classes. Firstly, those objects whose structural properties constrain the transfer path or act to change the material or equipment during transfer. For example, size and shape of a building combined with the plant layout constrain the transfer path, while weather conditions may adversely affect the material and/or handling equipment. Secondly, those elements of the organisation within which the handling activity is being performed. These may include management activities, maintenance activities, design activities, and so on.

From these basic definitions, two additional definitions are derived.

(i) A Handling System: a set of interrelated items of handling equipment, a regulator, and resources each of which is related directly or indirectly to every other item, and no subset of which is unrelated to any other subset.

Hence a handling system is an entity composed of a regulator, resources, and one or more items of handling equipment and relations between them. Items of handling equipment are commonly related by structural properties of the material, rate of transfer of the material, timing of a handling activity, and their separate structural and functional properties.

(ii) A Handling Process: a sequence of handling activities performed by a handling system on an item or items of material.

3.3 Interactions Between the Components of a Handling Situation

Figure 3.2 identifies six lines of interaction between pairs of components of a handling situation. Using the preceding definitions each interaction is examined separately to identify its characteristics.

(1) Material-Transfer Path: this interaction is geometrical and is contained in the definition of a handling activity.

(2) Material-Environment: changes in essential structural properties of the material caused by the environment (or vice versa) could be undesirable thereby requiring provision of suitable protection of one from the other. For example, passenger baggage must be protected from rain during transfer to and from aircraft at an airport.

(3) Material-Equipment: the material interacts physically with the containment or grasping component of the handling equipment. For example, they may interact chemically, or thermally, or if the material was abrasive it may wear the containment component, and so on. Furthermore the material may interact undesirably with other components of the handling equipment such as extreme wear caused by entry of abrasive materials into power generation or transmission components. In these cases adequate protection must be provided.

(4) Equipment-Environment: changes in structural properties of the equipment or environment may be caused or produced by their interactions. For example handling equipment operating outside may need to be protected

from weather, while equipment operating indoors alongside people must not pollute the atmosphere with exhaust fumes or excessive noise. The environment may change the function of the handling equipment, for example management may remove an item of equipment from service thereby changing its function from a producer to a non-producer of a handling activity.

(5) Equipment-Transfer Path: the shape of the transfer path is initially determined by geometrical properties of the material, however since the material and equipment are not separable during a handling activity the equipment will also affect the shape of the transfer path. Typically size and manoeuvreability of equipment within the environment affects the shape of the transfer path.

(6) Environment-Transfer Path: geometric properties of the environment constrain the shape of the transfer path because the material may only travel along certain specified routes.

Relationships between components of the handling situation are not limited to those arising from paired interactions. Two sets of relations arise from interaction between three components.

(1) Material-Transfer Path - Handling Equipment:

Physically, interaction between these components appears as a sequence of events beginning with locating and grasping or supporting the material, followed by a transfer along the desired transfer path, and ending by positioning and placing the material at the correct termination in space and time, in accordance with some pre-determined plan. For the purpose of analysis, three phases of the interaction can be identified for each handling activity:

(a) Locating and grasping the material.

(b) Material transference along the transfer path.

(c) Positioning and placement of the material.

These are the gross necessities of the interaction. Accuracy of positioning, timing of the transfer, and rate of material transfer are all important variables describing this interaction, therefore selecting equipment to perform a handling activity will require these phases to be identified.

(2) Material - Handling Equipment - Environment:

In situations where protection is required to prevent undesirable interaction between the material and environment, it is possible for the equipment to provide the protection required. Covers fitted to trucks to protect their loads from weather is a typical example.

The foregoing definitions will be used throughout the remainder of this thesis, in particular during development of a design strategy in chapter nine.

CHAPTER FOUR

DESIGN AND MATERIAL HANDLING SYSTEM DESIGN

4.1 Introduction

Designing in manufacturing organisations is an important activity which engages the attention of technical specialists such as professional engineers, technicians, and draughtsmen. Production of quality designs is crucial for economic success of manufacturing organisations, therefore designers must possess sufficient knowledge and understanding of the relevant technologies.

The act of designing may be envisaged as an information processing activity, thus to produce a design requires an information processor (a designer), a processing procedure (design method), and appropriate information. If one is to consider improving the productivity of a designer then it is necessary to:

(1) Improve the design method by developing a more logical method which is less likely to produce errors, and/or by increasing the speed of execution.

(2) Improve the design information.

Computers can improve a human designer's productivity by executing the design procedure more rapidly than can a human, and by efficiently storing and accessing design data. But before being applied to solve design problems they must be provided with both a procedure and relevant information.

This chapter will begin by identifying essential properties of generalised design activities, which are not always apparent in practice.

Since this project is concerned with designing a system, particular difficulties associated with systems design are examined. Finally, characteristics of material handling system design problems are examined and a general design strategy proposed.

4.2 The Design Process

Design as a process is initiated when the designer becomes sufficiently motivated. Motivation may be self-induced or it may be induced by another person such as a client, and arises from a desire to create a system which will perform tasks better than existing systems can.

Consider, for example, unloading a diecasting machine. Historically this activity has been performed by people in conditions which are often unhealthy and uninteresting. Insight and intelligence then combined to create an industrial robot which contains the essential abilities used by man to unload the machine, but excludes his frailties. The robot is unaffected by hot, smokey atmosphere, and operates tirelessly performing the handling task better than man.

This example illustrates one essential component of the design process, namely, creativity. In other words given sufficient motivation to set a goal, the designer must be creative to produce a design. Churchman (13) describes the creative act as one which attempts to identify different sets of actions capable of leading to this desired goal or set of goals. He also identifies two additional characteristics of the design process:

(1) It tries to estimate in thought how each alternative set of actions will produce a specified set of goals.

(2) Its aim is to communicate these sets of actions to other people who can implement them to produce the goal(s) in reality.

The design process can therefore be conceived as proceeding by four sequential activities; (1) motivating the designer to identify a set of goals; (2) creating different sets of actions capable of producing each goal; (3) evaluating each set of actions as to how efficiently it produces that goal; and (4) producing a message describing essential features of an object or system which satisfy the initial goals. The design process does not necessarily proceed in this order, finishing one activity before passing on to the next, since the designer may return to one of the previous activities to affect a modification. This is illustrated in Figure 4.1. The particular sequence in which this process is performed, is the design method.

These activities are consistent with the rigorous definition of a design situation proposed by Graeme Britton (14).

"A purposeful individual (A) designs, if in a choice environment S in a time-period $t_1 \rightarrow t_2$:

(1) A produces a message O_1 connoting two or more essential properties $\{p_x\}$ of a concrete system(s) or object(s), which does not exist in any environment at time t_1;

(2) the message (O_1) is a potential producer of at least one essential structural property of the system(s) or object(s) in some environment S_j;

(3) at time t_1, A is not aware of the complete set of properties $\{p_x\}$ but is aware of a subset $\{p_1\}$;

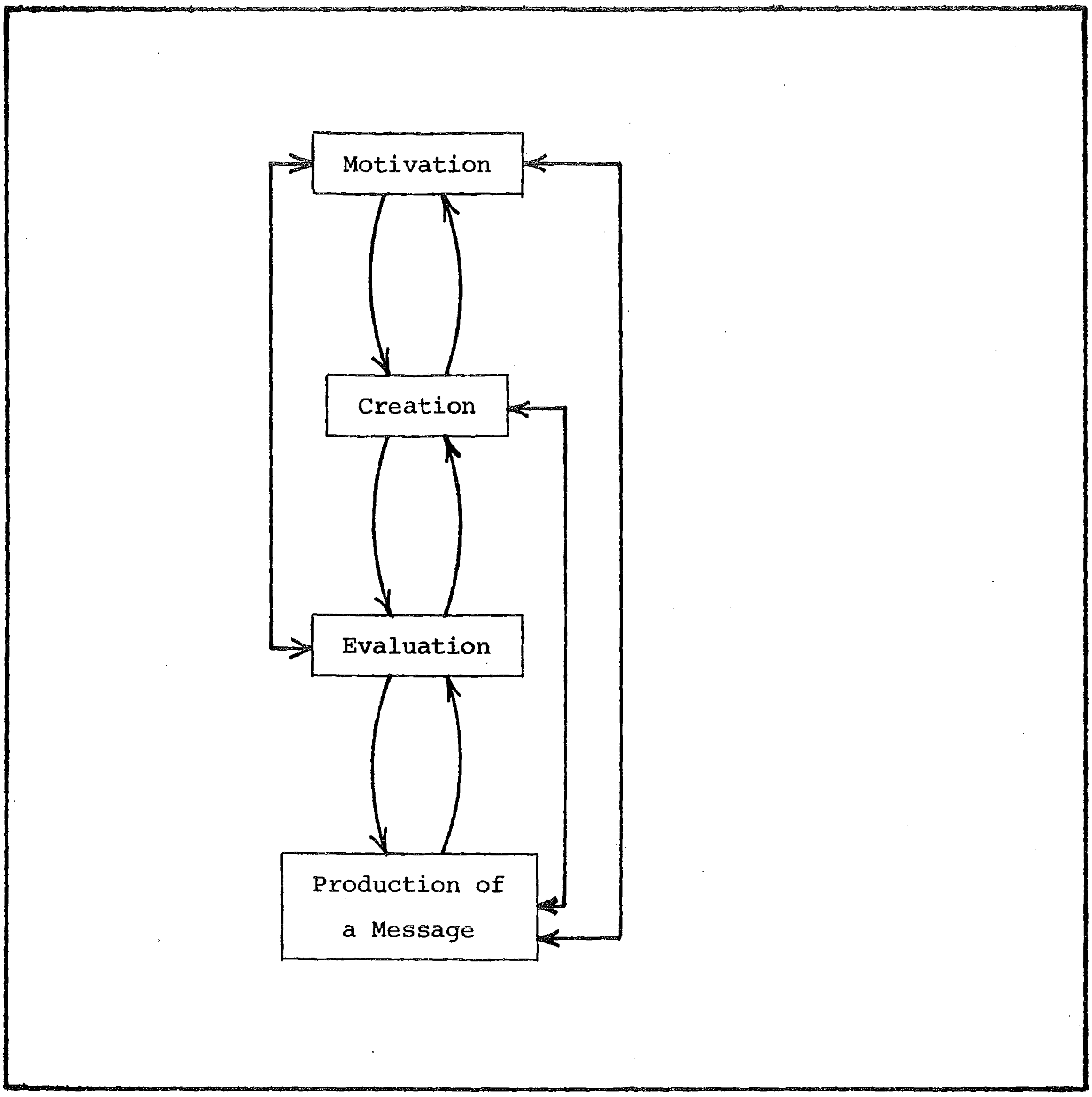


FIGURE 4.1 THE COMPONENTS OF THE DESIGN PROCESS

(4) during time-period $t_1 \rightarrow t_2$, A does not perceive a set of properties $\{p_s\}$ in S such that the union of $\{p_1\}$ and $\{p_s\}$ exhausts $\{p_x\}$.

The set of properties $\{p_x\}$ is the design".

Creative and evaluative activities are important in the design process because much of the designer's effort is expended performing them, thus a more detailed examination is necessary.(15)

There appear to be two modes of mental activity possible in the creative phase, namely, intuition, i.e. an unconscious inferential process, and thought, i.e. a conscious inferential process. For our purposes thought processes may be regarded as choice processes related to freshly perceived sensual stimuli, or through memory to previous experience. As long as the complexity of interactions and the choices in these thought processes can be expressed logically the necessity for intuition may be avoided. The mechanism of intuition is not well understood.

Thought and intuition play an important role in creative activities performed by human designers; chapter five will therefore examine these and other mental attributes used by humans to solve problems.

Evaluation may be on an objective basis, that is on a clearly defined and measurable basis, or on a subjective basis, that is depending on a person's feelings or his untested beliefs. There appear to be four main headings under which evaluations are made: (1) that the object or system in its operational environment will not require technical constraints or scientific truths to be violated; (2) that as ranked in the designer's or his client's economic/political value system it is adequate; (3) that it does not violate the moral values of society as determined in laws or if the client's system of moral values is wider than that determined by law that it is adequate in his system; (4) that it is adequate in the client's system of aesthetic values. Obviously evaluations of type (1) may be made objectively in the design process as long as the limits of existing technology and the designer's knowledge and understanding of it are not exceeded. If the limits of existing technology are exceeded objectivity may be maintained by development and testing in the appropriate environment. If it is the designer's knowledge and understanding which are the limiting factors, education and/or guided experience in the given choice situation may be required.

Evaluations of type (2) may be made objectively if the relevant economic factors in the client's system of value are clearly defined. Otherwise the designer must evaluate his proposals for the system on what he believes to be his client's feelings or he must put the choice directly to his client; in either case the choice is made subjectively.

Evaluations of type (3) are similar to those of type (2) in so far as "clearly" defined legal determinants may be regarded as objective criteria whereas all other factors are subjective.

As far as can be ascertained, aesthetic values (type 4) are all subjective and evaluations may only be judged on the basis of the designer's beliefs about his client's feelings or directly by the client.

Evaluations based upon objective factors that are clearly defined and measurable could be expressed in logic but we know of no way to make logical the evaluation of subjective factors.

Application of computers to aid design processes appear to be limited in both the creative and evaluative phases. In the creative phase only those sequences which can be expressed logically using a known set of properties are susceptible to computer aid, whilst in the evaluative phase only those sequences which can be evaluated objectively are susceptible to computer aid. Therefore the role performed by computers in any design process is dependent upon identifying logical decision sequences and objective measures for the variables necessary to describe the design situation. Decisions requiring intuition and/or subjective evaluations are most easily performed by the human designer. There can be no fixed criteria for assessing whether a particular sequence of decisions can be performed logically and objectively or not. Usually economic criteria limit time and effort which can be expended in research to identify logic and make objective relevant variables.

4.3 Designing Systems

This research is concerned with designing systems; specifically material handling systems. Systems are structures having organised components which introduce one central problem in their design. This can best be illustrated by way of an example.

In the forestry industry in New Zealand, selecting equipment for felling trees can be considered as designing a system. The designer may view his task narrowly constraining his thoughts to the selection of particular items of equipment commonly used in felling operations. He will be concerned with selecting chainsaws, the provision of spare parts, fuel, servicing, men, and so on. But the designer may consider a broader view; whether this man-equipment system is not simply a component of a larger system, the harvesting system. Thus the designer may wonder whether his design task may influence and therefore include changes in the planning system, trimming and topping system, skidding and hauling system, delimbing and bucking system, sorting system, and loading system. Still more broadly, he may see the harvesting system as one of several systems in a forestry system, components of which include a tree growing system, a harvesting system, a transportation system, manufacturing and processing system, and a training system. If he perceives his task in the narrowest sense, then he tells himself that the larger system is not his concern; how and where trees are planted and tended, what transport is normally used, is entirely up to scientists and senior managers. As far as he is concerned, larger systems are not relevant to the effectiveness of his choices.

Thus one important system design problem is to decide how large the system is, i.e. its components, boundaries, and environment. A closely related problem is determining the basic components of the system, that is the components that do not contain sub-components. For example when designing a felling system the designer should not consider the mechanics of chainsaw engines since this is entirely up to the chainsaw manufacturer. In this case the chainsaw or its spare parts are the smallest component.

To the four characteristics of design given above must be added a fifth which is specific to systems design: the systems designer attempts to identify the whole relevant system and its components; each design alternative is defined in terms of the design of the components and their relationships. Thus a handling system design method must include criteria for identifying the system, its components, and the components of the environment.

4.4 The Design of Handling Systems

The objective of a material handling system designer is to specify the structural details of an adequate handling system. For most industrial handling systems the design consists of a description of a set of standard items of handling equipment, such as conveyors, cranes, trucks, and the like, most of which are commercially available in a range of capacities. Experience indicates that the creative aspects of designing a handling system differ from inventing a new machine whose functional and structural properties are entirely novel, at least to the human designer. However what is novel and therefore creative in a handling system design is the system, even though its components may be standard items of handling equipment. The design method may therefore be envisaged further as matching essential properties of a handling activity and its environment to essential properties of items of handling equipment. In other words, as a process of defining essential properties of the handling situation.

What does this mean in terms of design strategy? Combining the philosophy on problem solving discussed in chapter two, and the characteristics of system's design identified in this chapter the following design strategy suggests itself.

Given sufficient motivation to produce a design, the designer should begin by identifying general functions which must be performed by the handling process. These may be determined by manufacturing processes for example which provide the need for performing handling activities. In the logging example used earlier, the general functions of the harvesting system are to transform trees positionally and structurally from their growing position in a forest to trimmed and sorted logs ready for transport to a sawmill or pulpmill. General functions of harvesting include:

(1) Planning - time to plan, build roads, construct landings, and allow ground to consolidate.

(2) Felling.

(3) Trimming and topping.

(4) Skidding or hauling.

(5) Delimbing and bucking.

(6) Sorting and stockpiling.

(7) Loading onto transport for transfer out of the forest.

Having identified the general functions, the designer can identify specific handling functions which must be performed, that is the handling activities. In the above example these include:

(1) Felling - changes in orientation of the trees from standing vertically to lying on the ground.

(2) Skidding or hauling - change in position and orientation of logs from forest floor to delimbing area.

(3) Sorting and stockpiling - change in position and orientation of logs into classes depending upon the properties of each log.

(4) Loading - changing the position and orientation of logs from stockpiles onto trucks.

Describing these functions requires a more detailed knowledge of processes and materials than does describing the general functions.

Each specific function indicates a sequence of actions and constraints upon these actions. For example felling involves lowering actions which may be uncontrolled when the tree falls to the ground, or they may be controlled by a mechanical device such as a wire rope system or feller - buncher. Constraints on these actions include felling rates, number of people, number and types of machine, fuel, influence of terrain, tree size and shape, stand density, probability of tree breakage, and so on.

Using these actions and constraints the next logical step is to identify general structural properties of objects capable of performing these actions. For example cutting actions are performed by saws or shears, controlled felling operations are performed by feller-bunchers or winch-wire systems. Each of these classes of equipment will be subject to the constraints identified.

Having identified general classes of equipment the designer must specify individual members of each class which satisfy the specific functions and constraints. For example, in the felling activity the designer may identify feller-bunchers as a class of suitable equipment in which case he will have to identify the size, capacity, felling rate, make, model and so on that can produce the actions required within the constraints. This represents a technically feasible solution. Selecting between several technically feasible solutions requires that other criteria such as economic and legal, be considered.

A design strategy for identifying technically feasible solutions comprises four stages:

(1) Identifying the general functions required of the system, i.e. the handling process.

(2) Identifying the specific functions of the system, i.e. the actions and constraints relevant to each handling activity.

(3) Identifying the general structural classes of equipment necessary to perform these actions, i.e. classes such as robots, trucks, cranes, conveyors, and the like.

(4) Identify specific items of equipment capable of performing the actions for each handling activity.

Each of these stages will require creative and evaluative activities.

CHAPTER FIVE

THE HUMAN DESIGNER

5.1 Introduction

People produce designs for material handling systems which are technically and economically satisfactory. Although attempts have been made (1) to formalise the design method, success has been very limited; the human designer appears to be necessary. The specific attributes a person possesses which enable him to perform a design activity are an interesting subject for speculation. To discuss this subject a model of human behaviour developed by Ackoff and Emery (6) is examined.

This model was chosen because it provides a rigorous defined system of concepts definitions which to explain human behaviour. From this system those attributes essential for producing a design are identified.

Central in this model is the choice situation which explains how a purposeful individual acts when confronted with two or more unequally desirable outcomes, and associated with each outcome one or more unequally efficient courses of action capable of producing it. Essentially this is the situation confronting handling system designers because he must choose one or more items of handling equipment to perform a handling activity.

Using the choice situation the particular case of the problem situation is examined to identify mental abilities used to solve problems.

Finally Ackoff and Emery's model describing how people inquire and the manner by which mental models of reality are formed is presented.

5.2 Human Attributes in Problem Solving

An essential characteristic of purposeful behaviour is that it involves choice. A purposive situation ~~state~~ is characterised by four components. These are; (1) the subject (the designer) that displays choice, (2) the choice environment which includes factors the designer takes into account when making his choice, (3) the available courses of action which are methods the designer may use to produce a design, (4) the outcomes possible in that environment, namely designs describing satisfactory systems of handling equipment. Relationships between these components are completely specified by three types of measure that are parameters of the purposive state. These are; (1) the probability of choice, that is the probability the designer will choose a particular course of action, (2) the efficiency of a particular course of action for producing a design, (3) the relative value of each outcome to the designer or his client.

The designer and/or his client may be dissatisfied with the performance of an existing handling system. They may also be doubtful about how to produce a design which removes their dissatisfaction. Ackoff and Emery defined the particular case of a choice situation in which a purposeful individual is both dissatisfied, and in doubt about what course of action will change that state to one of satisfaction, as a problem situation. Consider this in detail.

Problem: A purposeful state that a purposeful individual is dissatisfied with, and in which he is doubtful about which of the available courses of action will change that state to one of satisfaction.

The designer as a purposeful individual has three ways of disposing of a problem: dissolution, resolution, and solution. Consider each of these in turn.

Dissolving a Problem: The designer, upon inquiring into the source of dissatisfaction over the performance or non-performance of a handling activity may change his intentions so that his dissatisfaction dissolves. For example, the designer may intend performing a handling activity but upon inquiry may change his intention by resiting manufacturing plant, thereby dissolving the design problem.

Resolving a Problem: The designer may be aware of several available design methods each of which appear to produce the outcome he desires with equal efficiency. He removes the problem by making an arbitrary choice.

Solving a Problem: Solving a problem involves answering two questions: (1) What alternatives are available? (2) Which one is best or good enough? Any alternative which replaces dissatisfaction in the designer with satisfaction is a satisficing solution. An available solution which produces as much or more satisfaction than can any other solution not only satisfices but optimises. Therefore, solving a problem involves selecting one of a set of available courses of action such that, as a result of inquiry, the designer believes it the most likely to provide a satisfactory solution and which in fact does produce a satisfactory solution.

Each of these cases may dispose of the designer's problem; however, neither dissolving nor resolving involve designing the handling system. Dissolving a handling problem would involve designing the manufacturing and/or supply and distribution system. Problem solving is therefore examined in detail.

Identifying combinations of handling equipment capable of producing actions required in a handling activity is an essential part of designing. The designer may produce a new design using a familiar design method or he may find a new method. The newness of these discovered alternatives implies that a creative act has occurred, therefore an understanding of the role of creativity in formulating solutions to handling design problems is necessary.

The first human ability considered is inference. Ackoff and Emery provide the following definition.

Inference: the production of one or more beliefs or assumptions by one or more beliefs or assumptions.

An inferential process is always about something - some class of objects, events, or situations, or combinations of these. As has been stated for the handling situation, the design task involves the components; material, transfer path, environment, and handling equipment. These are the components the designer believes are relevant to his choice. Therefore the first part of a formalised inferential process is a set of components the designer believes are relevant.

The second part of a formalised inferential process is a set of beliefs concerning the form in which relevant beliefs can be presented, that is, the relevant form of the relationships between the components.

Thirdly there is a set of beliefs and assumptions that the designer initially accepts as true. In other words a set of accepted facts or observations sometimes referred to as the premises of the design task.

Fourthly and finally, there is a set of beliefs concerning how acceptable beliefs may be derived from those accepted. These beliefs constitute the design method.

The inferential process may be envisaged as occurring along a continuous scale. At the extremities are the particular processes of thought and intuition. Thought is associated with an orderly and logical construction of the components of the inferential process, whereas intuition at the other extreme is associated with a mental leap over an inferential gap. Consider brief definitions:

Thought: is conscious inference.

If the designer employs an inferential process and is conscious of its parts; the objects and/or events, relationships between them, premises, and design method, he can be said to be thinking. Thought can be used to evaluate courses of action in a systematic way.

Intuition: is unconscious inference.

The designer may be unconscious of any part or all of the inferential process employed. It may be noted that few if any inferential processes are either pure thought or pure intuition.

Intuition supplies many possible beliefs, hunches, conjectures, suggestions, and so on, which thought can be used to evaluate systematically. Thought is an evaluative process in which the values involved are based upon the true-false scale. Intuition does not evaluate, it proposes. Thought proves.

Ackoff and Emery suggest two parameters to describe the human evaluative process used to obtain a solution to a problem: consciousness and programmability. Consider four categories arising from the two states of each parameter in Figure 5.1.

Although random selection and guessing as a means of problem solving are introduced here, they are not relevant to the search for a logical handling system design procedure.

Thus far only the case where a solution to a problem is actually available has been considered. For completeness the case where no solution is available is considered briefly.

	Conscious	Unconscious
Programmable	Thought	Intuition
Unprogrammable	Random	Guess

FIGURE 5.1 FOUR CATEGORIES USED IN EVALUATION

If the designer believes none of the available courses of action of which he is aware can work he has two alternatives available to him. Firstly he can search for another course of action which is available but of which he is not initially aware. Secondly, he can develop a new instrument and associated course of action. Two definitions clarify these cases.

Search: One or more observations whose intended outcome is awareness of a course of action that the designer was not aware of before making the observations.

Develop an Instrument: to produce an instrument in an environment which makes possible a course of action which was not previously available in that environment.

Thus through search or development a purposeful individual can convert a state of dissatisfaction which he initially has no control over into one he does control.

Once a model of a handling activity for which a handling system is required, is accepted by the designer he can proceed to choose a design method or course of action. Intuition suggests possible courses of action that can be evaluated by use of the choice model and the thought process. The model the designer constructs of the handling situation is the product of past and present observations (possibly coloured by predictions based upon experience) or, more generally, perceptions. The consequences predicted by the model (without actually building the system) are evaluated by feeling. A course of action that is predicted to yield satisfaction is selected.

Apparently the human designer makes use of thought, intuition, perception, and feeling in making a choice. Ackoff and Emery propose a pattern of inquiry based upon these attributes. This pattern is summarised as follows:

(1) A choice situation is a necessary antecedent of a problem. A choice situation becomes a problem situation only if the designer (or his client) is dissatisfied (a feeling) and is doubtful about what to do.

(2) Furthermore, unless the designer (or his client) responds to the possiblity of choice, and is aware of it, a problem cannot arise. This awareness as well as a state of doubt and dissatisfaction is necessary before the individual can be said to have a problem.

(3) The role of perception is to provide information. This affects possible choices. The contributions of the senses, present and past, when believed or assumed provide the designer with the raw material from which a model of the handling situation is constructed.

A solution is produced by a course of action, a design method. The perception of a possible course of action when it just "occurs" to the designer, is a product of intuition. Alternatively, a course of action may arise from thinking about the situation based upon what is known or believed about the situation.

(4) The designer's inputs to the problem situation of perception and feeling are evaluated by thought. Evaluation here means whether or not a suggested course of action will produce a desired outcome in the situation involved. Possible courses of action can be evaluated either by predicting their consequences by using what is believed about the situation (a thought process), or by trying them and observing the consequences and evaluating them (feeling).

(5) The choice process has no fixed sequences or number of steps. One choice (and problem) situation arises out of another in a continuing stream. Several problems may coexist and interact. Hence the process of choice as performed by human designers is very rich; it can be infinitely varied. It is a process in which each step can be fed back to every other.

The foregoing analysis describes how a person disposes of a problem situation. Emphasis was placed upon solving a problem which was shown to require an inferential process if the solution was to be achieved logically. Also an inferential process demands a model of the problem situation, therefore it is appropriate to examine how a purposeful individual models a problem situation.

In chapter three the difficulty of deciding which properties should be included in the description of components of the handling situation was mentioned. If the designer is to develop a model of the situation then he must be able to distinguish those properties which are relevant from those which are not. This is important because what a designer perceives in a situation is not merely a matter of what is given to him by the situation, because much more is offered than he can possibly receive. Therefore, what he perceives is also a matter of what he takes. He enters the situation with a model of the situation albeit crude, but which provides him with criteria of relevance and hence influences what he looks for.

A purposeful individual's model of the handling situation is a set of structural and functional properties together with relationships between them which he believes are necessary to define it. The designer generates his model by using three attributes; (1) perception, (2) consciousness, (3) memory. Perception enables him to respond to a stimulus received through the senses while consciousness allows the perception of the mental state of another person or oneself. Memory enables the designer to respond at some time later to something he has sensed in the past. Through memory experience can come into play at a later date.

Thus the combination of perception, consciousness, and memory provides a description (an image) and an explanation (a concept) of the handling situation, which generates a set of beliefs about the situation that are organised into a model of it. The reason for using a model is that images and concepts are easier to manipulate than is reality.

Therefore the designer must begin with a model of the handling situation. If the model is a poor representation of reality, then by perceiving properties of the situation he may improve his model. If he has been confronted with a similar situation in the past, and recognises it as similar, then he may use the model stored in his memory. The level of experience is determined by how accurately the model in his memory represents the situation of current interest. An experienced designer possesses in his memory a model that is very similar to a handling situation of current interest. All that is needed is for him to perceive each property and to manipulate the model by thought and intuition. If inexperienced he must supplement his model by perceiving properties that he believes are relevant and testing them in his model for relevance.

CHAPTER SIX

APPLICATIONS OF DIGITAL COMPUTERS TO DESIGN SITUATIONS

6.1 Introduction

There is a growing body of literature on computer aided design and in some instances integrated sequences of the design process have been automated. However the characteristics of design problems which enable part or all of the design process to be automated are not clear, therefore the objective of this chapter is to identify these characteristics in problems where computers have been successfully employed. Four engineering design case studies are examined.

In concept most handling system design problems are selection problems. That is given a description of the handling activity and environment, select a suitable handling system capable of performing the handling activity. The case studies chosen involve selecting objects or events given an initial description of the problem.

Each case study is examined in the following way which makes explicit the choice situation confronting the designer.

(1) A brief outline is given to introduce each problem.

(2) The designer is dissatisfied with the present state of an existing system and is doubtful about how to change it to a satisfactory system. Objects and events which the designer are dissatisfied with are identified.

(3) The components of the problem situation which affect the designer's choice of solution are enumerated.

(4) The set of objects or events from which the designer chooses a solution are identified.

(5) Inevitably there will be several design methods available which yield a solution. Constraints which limit design procedure are examined.

(6) Finally, the design procedure developed for use on a computer is studied.

6.2 Case Study One - Automatic Design of Systems to Avoid Torsional Vibration Troubles. (16)

This case study is concerned with one aspect of the design of medium speed diesel engine installations, namely, adjustment of various engine-load parameters to avoid harmful torsional vibrations during normal engine operation. Prior to development of the computer routine by the authors, attainment of a satisfactory solution demanded the experience of a skilled designer, which even in simple cases, proved time-consuming, repetitive, and expensive.

The purpose of the research was to develop a computer program capable of accepting relevant properties of both engine and load (say an alternator set) and from these properties select a combination of flywheels, drive shaft, and damper. Selection criteria were that the solution had to be feasible, safe, as economical as possible, and above all, free from excessive vibration amplitudes.

A solution comprised a combination of four standard components:

(1) The drive shaft connecting engine and load.

(2) A tailend flywheel for tuning natural frequencies of torsional vibrations.

(3) A viscous torsional vibration damper.

(4) The engine flywheel.

Each component is available in known standard sizes which vary in cost according to their size; the larger a component the more expensive, thus making its selection less desirable.

Consider formally the problem situation facing the designer.

(1) The designer is dissatisfied because he is aware of the possibility of failure which may be both dangerous and expensive if the engine-load system is not free from excessive torsional vibrations.

(2) The designer is doubtful about what course of action will lead to a successful solution. Experience gained from solving similar systems enables him to develop a satisfactory solution by checking several provisional designs, which for simple cases, proves time-consuming.

(3) The choice environment confronting the designer includes the following objects:

(a) engine-load combination,

(b) tail flywheel

(c) viscous damper

(d) flywheel, and

(e) driveshaft.

Classes of problems and solutions are defined by known finite sets of properties from which individual problems and their solutions can be defined. For any particular problem the designer can obtain a solution from a set containing about five different flywheel inertias, for both main and tailend flywheels, four different dampers, and a specified range of drive shaft stiffnesses.

(4) A possible solution includes any combination of drive shaft, tail flywheel, viscous damper, and flywheel from the standard range of each available. Only a few such combinations, however, produce a solution which satisfies the dynamic conditions; only one of these minimises cost and is regarded as an optimum solution.

(5) The design method used to select a solution will depend upon the designer's experience. The method chosen takes the form of a mapping between properties describing the engine-load system and the set of possible solutions. Two features of this mapping are important; firstly the relationships existing between property sets describing the problem and solution, and secondly, the order in which these relationships are applied during the mapping process. Experienced designers were aware of the variables necessary to describe the situation as well as relationships between them. These were derived from vibration theory, and indeed computer routines were available for performing certain calculations. For example, the calculation of the natural frequency of a system of inertias, stiffnesses, and dampers in a torsional mode is well known in vibration theory. However, the difficulty all designers experienced was to choose the order of applying these relationships. For example, the designer had to guess a particular flywheel inertia and shaft stiffness from those available and proceed to calculate critical speeds for a particular mode before modifying his guess and recalculating critical speeds, until no critical lay within a band of ±15% of normal operating speed. Although calculation procedures were well known, the process of guessing possible solutions proved both time-consuming and expensive.

(6) The preceding five points identify essential features of the problem situation confronting the designer each time an engine-load system needs designing. Because this task was performed often, considerable aid could be provided to the designer if a computer routine could be made available.

The critical aspect of providing a design aid lay in development of a logical selection scheme to replace the designer's need to guess possible solutions. This required searching for a consistent pattern in which to apply mathematical relationships known to be relevant. If such a pattern existed, how could it be detected? In this case many satisfactory designs were studied to determine the order in which human designers had selected solution elements, what calculations had been performed, and constraints used to make each decision. The flow diagram given in Fig. 6.1 outlines the algorithm resulting from this examination.

In summary, logic incorporated in the computer routine was developed by examining many actual design situations where satisfactory solutions had been obtained. Decision rules were recognised and made explicit which enabled development of an algorithm capable of selecting optimum solutions. Finally the computer routine was tested in actual design situations and was shown to produce accurate results more rapidly and economically than had previously been possible.

6.3 Case Study Two - Computer Generated Tooling Arrangements for Turret-Type Lathes. (17)

This investigation was initiated with the purpose of developing a computer program capable of selecting tooling necessary to turn a specified product from a specified blank. The program was developed with particular reference to automatic, single spindle, multi-station turret lathes. Not only was it necessary to select appropriate cutting tools but also the program had to place them in an appropriate sequence on cutting stations available. Normally such a tooling specification was prepared by an experienced designer, the preparation of which proved both time-consuming and repetitive. Often quotations based upon the tooling specification, were accepted or rejected by prospective customers depending upon the promptness with which they were prepared; speed and accuracy in preparation of these specifications was vital.

Insofar as the designer produces a novel tooling combination as the result of his actions, then he can be regarded as designing in terms of the definition of the design situation given in Chapter Four. In every case the

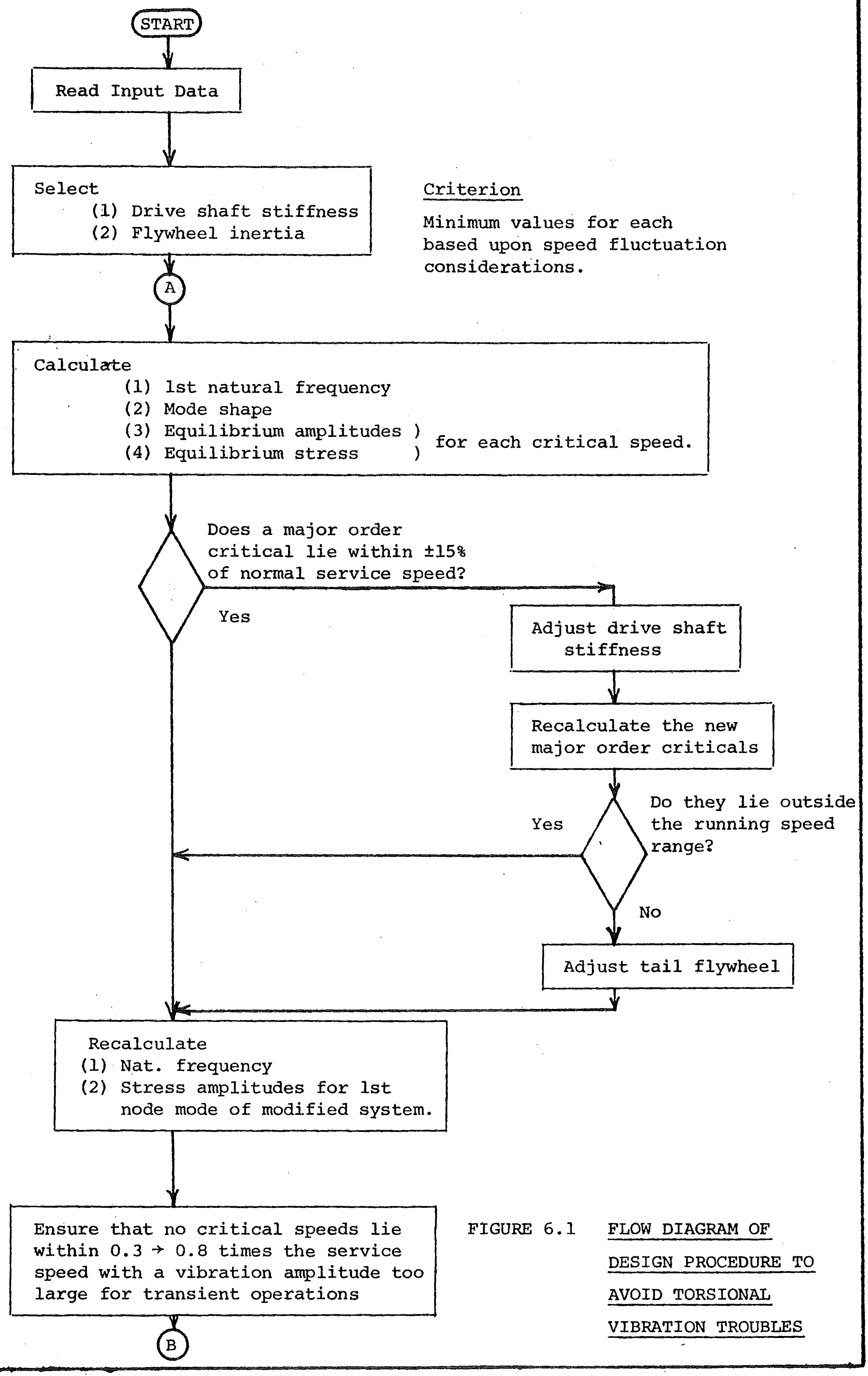


FIGURE 6.1 FLOW DIAGRAM OF DESIGN PROCEDURE TO AVOID TORSIONAL VIBRATION TROUBLES

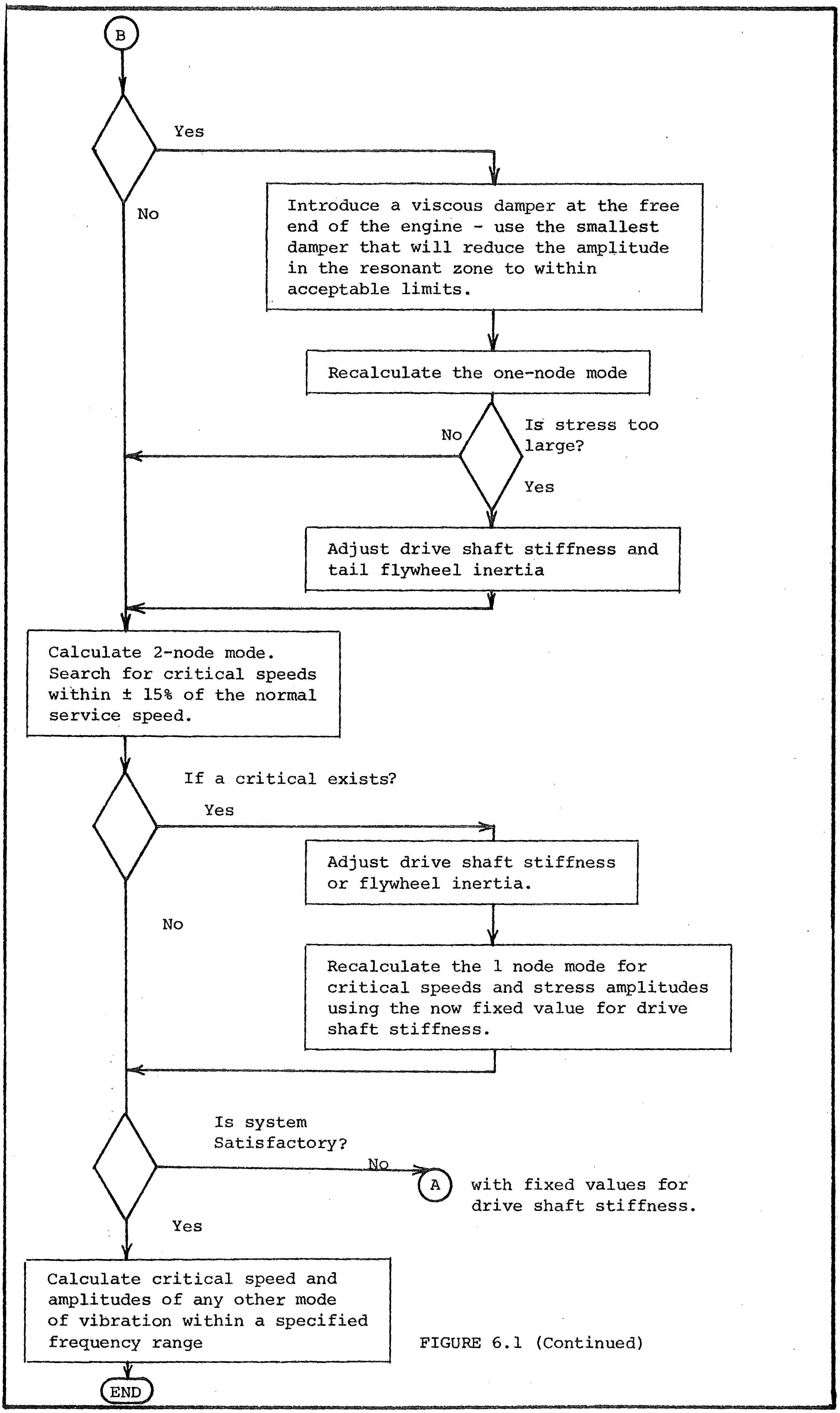


FIGURE 6.1 (Continued)

designer could describe the relevant properties of both material and lathe. The material had to be described both geometrically (before and after machining) and metallurgically (in terms of limiting cutting speeds and feeds). The lathe was described in terms of cutting stations available, tool feeds, and chuck speeds.

A solution was obtained by selecting tools from a known set which could generate the finished piece from a blank. Selection criteria demanded that tooling should be both capable of generating the correct geometry whilst minimising machining time. Lathe characteristics were such that power limitations rarely constrained tooling combinations.

For each tooling design task the designer faced the following problem situation:

(1) Dissatisfaction arises because the designer is not aware of the tools necessary, and the sequence in which they must be placed on the lathe, to turn a specified component from its blank.

(2) He is doubtful about how to determine the set of tools which will achieve the shortest machining time. Experience enables him to select a satisfactory tooling arrangement by examining geometry changes necessary to transform the blank into the finished piece.

(3) The designer's choice environment includes the following components:

- (a) A geometrical and metallurgical description of the unmachined blank. Normally the blank is barstock or a casting.
- (b) A geometrical description of the final component.
- (c) The lathe, described in terms of number of cutting stations, feed rates, and chuck speeds.
- (d) The set of cutting tools from which the designer can choose an appropriate subset.

Although the geometrical description of the blank and finished piece appears to present a major difficulty because of the large number of different shapes possible, in fact geometrical descriptions of turned components are highly constrained. Firstly all turned objects are solids of revolution and as such can be completely defined on a plane section through the axis of rotation, and secondly, by defining special features such as chamfers and grooves in cross-section a wide range of geometries can be accommodated. A number of different materials from which most components are made are listed and their machining properties tabulated. A wide range of turning tasks can therefore be described by finite sets of properties.

(4) A possible design is any ordered set of tools which can be mounted on the saddle cross-slide and turret of a lathe which produces the desired geometrical transformation. Although any such combination represents a physically feasible solution, economic factors demand an optimum solution. In this case the combination of tools which minimise machining time.

(5) The design method can be represented by a mapping between sets of properties describing the problem and a description of cutting tools and their sequence. Unlike the previous case study this mapping is not described by mathematical relationships but is specified directly. For example, holes with a length to diameter ratio of less than 1.5 are always generated by stub drills, internal threads are generated by taps, external threads by die-blocks, and so on.

Two phases are required to map the problem into the solution. Phase one begins by examining geometrical differences and selects tools capable of producing the geometrical transformation. Phase two involves placing the set of tools chosen onto appropriate machining stations on the lathe.

Two classes of constraint must be satisfied to allocate tools to machining stations. The first limits the number of combinations by considering geometrical compatibility of the group of tools, technological acceptability based upon good machining practice, and economics of choosing a suitable cutting speed. The second class considers constraints arising from placing a combination of cuts onto a particular cutting station. These include tool combinations causing unsatisfactory machining conditions, clamping difficulties associated with fixing tools at a machining station, and metal removal capacity of the lathe.

In summary, to successfully design tooling to machine a product, it is necessary to recognise what tools are needed to produce the desired geometrical transformation and to allocate these tools in suitable combinations to appropriate machining stations. The design process is constrained by material, the lathe, tooling available, and economics.

(6) If computer aid can assist the designer to select an optimum tooling arrangement then it must be able to encompass the preceding problem situation. Motivation to consider computer aid arose from several factors including the number of designs required, cost of producing each design, errors possible during designing, and time necessary to produce a design.

Geometrical and metallurgical properties were formalised by examining a range of existing products and extracting relevant features. In this manner a set of standard properties was available to describe any particular geometry and material.

Lathe feeds and speeds were tabulated in handbooks and no difficulty was experienced in making them available to the computer.

The most difficult parts to formalise were the constraints, which included apparently subjective factors such as good machining practice and acceptable machining conditions. To overcome this difficulty a system of numerical penalties was introduced. Two classes of penalties were devised. One class aimed at penalising geometrical incompatibility of groups of cutting tools, poor machining practice, and undesirable cutting speeds. The second class penalised poor tool combinations such as rough and finishing cuts being assigned to the same machining station, poor clamping arrangements, and excessive metal removal requirements. These numerical values were developed with aid from a person experienced in designing tooling layouts.

The design method was developed in the same manner as the first case study, by examining many examples thus enabling recognition of a pattern in the design process. Figure 6.2 illustrates this method. For simplicity no feedback loops are illustrated, but within each activity iterative procedures characteristic of designing are necessary.

6.4 Case Study Three - A Computerised Planning Procedure for Machined Components. (18)

The objective of the research examined in this case study was to develop a computerised planning system capable of optimising the selection of machine tools to manufacture turned components. Normally in industry a planning engineer or foreman uses his judgement, based upon experience, to select acceptable machine tools and manufacturing methods. Although experienced foremen can select technically feasible machining methods, there is little regard for optimisation. Indeed, the optimum method of manufacture may change depending upon whether production rate is to be maximised, or alternatively cost minimised. The large number of parameters which affect economics of machining suggests that to achieve the optimum manufacturing procedure it is necessary to store a large quantity of information and perform many calculations. Because of time involved to perform each design manually, use of a computer to aid this process must be considered.

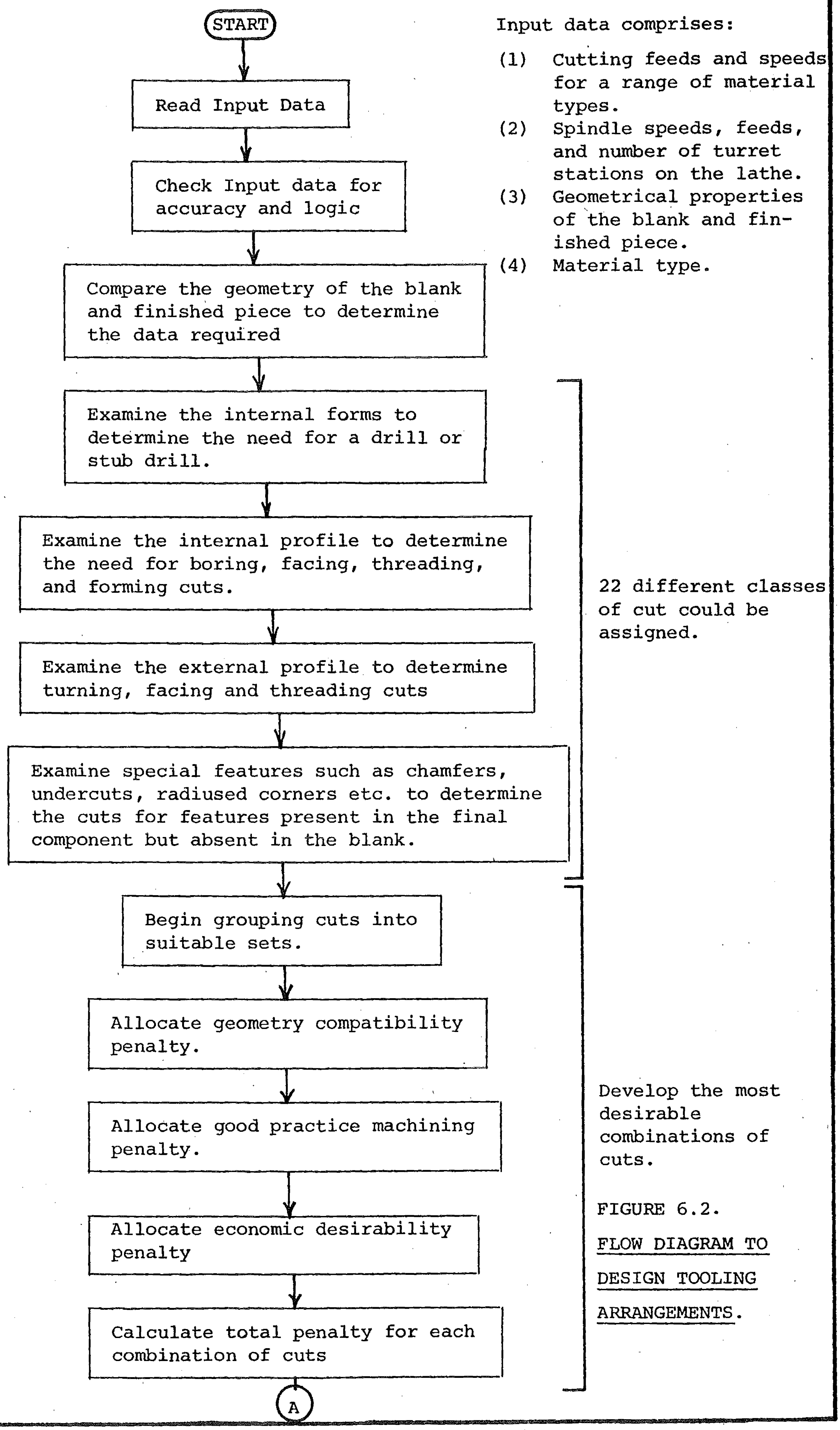


FIGURE 6.2.

<u>FLOW DIAGRAM TO DESIGN TOOLING ARRANGEMENTS.</u>

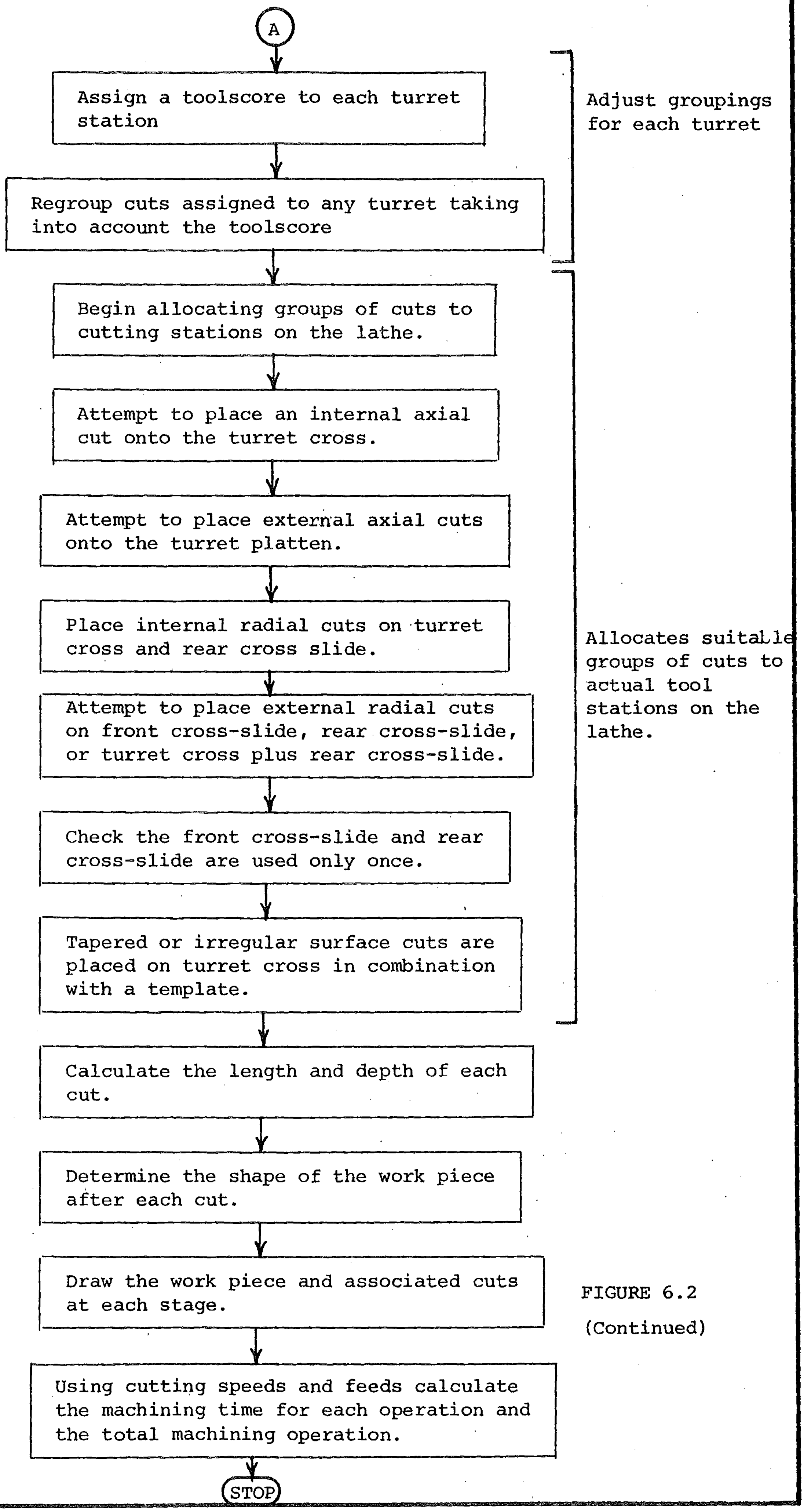


FIGURE 6.2

(Continued)

Any planning procedure to be effective must take into account the following classes of objects and events:

(1) Parts to be manufactured.

(2) Manufacturing machines available.

(3) Manufacturing processes possible.

(4) Manufacturing sequences available.

For every object manufactured the designer must specify its relevant properties, such as its geometry and cutting requirements, the machine tools available, and their cutting feeds and speeds. From this description the optimal combination of machine tools and manufacturing processes may be selected.

Although this example was developed for production of cylindrical components, the authors believe it can be extended to other machining processes such as milling and grinding.

(1) The designer is dissatisfied because he is unaware of optimal manufacturing processes and machining sequences to produce a specified component from a specified blank.

(2) Because of the large number of combinations possible, the designer is doubtful about how he can select an optimal combination.

(3) The environment within which the designer must make his choice comprises three components:

(a) A geometrical and metallurgical description of both blank and finished piece. Variables deemed relevant include material hardness, component dimensions and tolerances, surface finish and component quality.

(b) A description of machine tools available to the designer. Major descriptive variables include cutting speeds and feeds, machine size and capacity, available power, process capability, and production rate.

(c) Technological considerations such as tool life, tool wear, surface finish, chatter, work hardening during cutting, and other features which affect machinability and accuracy of metal cutting.

Relevant variables necessary to describe this problem situation were determined by detailed examination of a large number of components, machine tools, and technical papers describing technological aspects of metal cutting. Finite lists of variables were identified to describe most design situations.

(4) Any sequence of cuts which can be performed by the machine tools available represents a possible design. Economic demands require selection of an optimal solution based upon maximum rate of manufacture, or minimum cost.

(5) Relationships between the properties describing the problem are identified. Geometrical and metallurgical properties determine the set of cutting tools necessary. A cutting sequence depends upon geometrical transformations required and cutting tools available, while cutting feeds and speeds are selected according to material properties, tolerances and surface finish, and economics of tool life. Suitable machine tools are selected upon the basis of cuts required. If several machine tools are capable of producing the necessary cuts, then many machining sequences become possible. If the selection criterion is maximum production rate then the sequence of machining stations having least total time is selected; transfer and chucking times included. Alternatively, if cost is to be minimised then the sequence of machining stations each having the least cost is chosen.

(6) Computer aid is limited by the extent to which components of the designer's choice situation can be formalised.

Geometry of the material is defined using elementary cylindrical volumes whose surface diameter and length are specified. Tolerances and surface finish are given for each cylindrical element. Metallurgical properties such as material hardness and cutting rates are tabulated and easily coded. Similarly variables describing both cutting tools (such as tool life and wear) and machine tools (such as size and capacity, feeds and speeds, power, and so on) are easily tabulated and coded.

The algorithm which maps problem variables into solution variables represents the greatest difficulty. Two distinguishable parts are necessary to obtain a satisfactory mapping.

The first is concerned with determining cuts required. Component machining requirements are determined by evaluating relevant parameters associated with each geometrical feature, for example, surface finish, cutting forces, tool type, and work piece material are typical. Many of these parameters are interrelated and as such, the machining requirements are selected by an interative procedure. This means that an initial value assigned to a parameter may be updated by values of other parameters. For example the depth of cut affects machining time and cutting force, and is also related to component machining requirements, onset of chatter and allowable distortion. Any one of these parameters may be fed back to modify the depth of cut from its initial value determined from geometrical considerations. By iterating through the relevant calculations a suitable set of cuts is determined.

The second part involves selecting a suitable machine tool (or tools) and an appropriate sequence of operations. Machining capabilities for each available machine tool are tabulated in arrays in a form comparable to the cuts determined in part one. The computer steps through each cut matching it to each acceptable cutting station. Several possible solutions will now present themselves, each representing a practical manufacturing procedure. At this stage, the optimising procedure is invoked. If the optimisation criterion is to maximise the production rate, then the sequence of cutting stations, which individually minimse cutting time, is selected. If, however, the criterion is to minimise cost, then the sequence of cuts having least individual cost is chosen. Transfer times between machines and chucking times are automatically included.

The flow chart in Fig. 6.3 outlines the algorithm used to produce a solution.

6.5 Case Study Four - A Computerised Method for the Selection of an Industrial Robot for the Automation of a Working Place (19)

Since their recent introduction industrial robots have found useful application in the automation of industrial work places. Because they are novel there has been little experience gained in designing work stations using them. Within a period of about ten years many different robots have been manufactured commercially possessing a wide range of different capabilities. If a work station is to be automated with the aid of a robot, then the designer must identify the work tasks and select the robot which can perform them in the most economical manner. Currently the design procedure is not performed systematically and as such proves time consuming; an incorrect selection may be very expensive. Therefore development of a computer routine to select robots could provide a more logical, rapid, and reliable approach resulting in a better design.

Consider the problem situation confronting the designer.

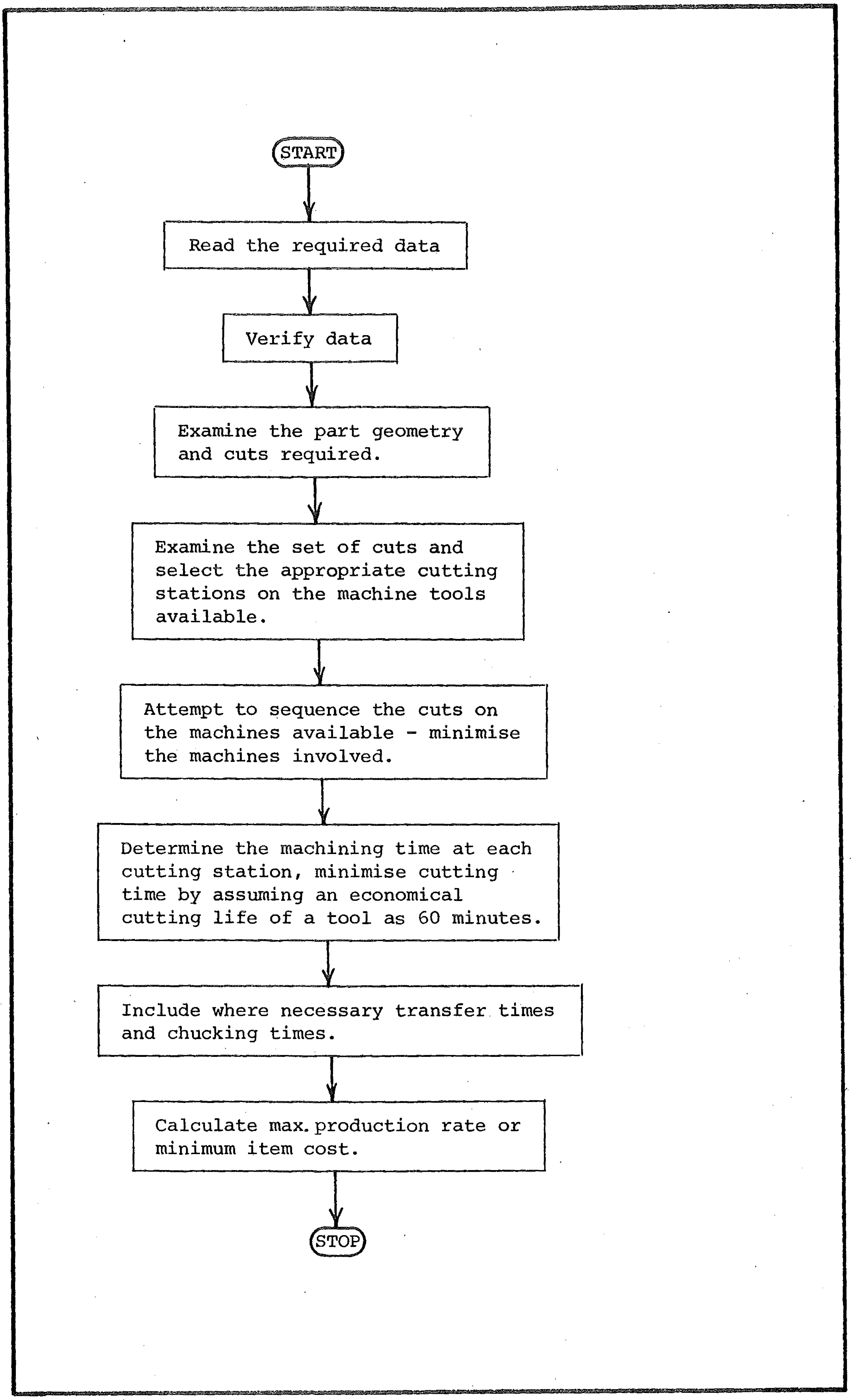


FIGURE 6.3

FLOW DIAGRAM OF PLANNING PROCEDURES TO OPTIMISE MACHINING PROCESSES

(1) The designer is dissatisfied with an existing work station and believes an automated arrangement may be more economical.

(2) He is doubtful about which work station properties affect the selection of a robot and therefore of its abilities required to perform the desired tasks.

(3) The designer's choice environment includes objects and events from each of the following four classes:

(a) Work task.

(b) Material being processed.

(c) Physical environment surrounding the work place.

(d) Commercially available industrial robots.

If the designer is to obtain a satisfactory solution within this environment, he must take into account the number of combinations or properties occurring in each class. Consider this variety. The work task itself may be considered as comprising six classes of actions:

(a) Machining;

(b) Set-up;

(c) Tool handling;

(d) Maintenance;

(e) Supervision; and

(f) Auxiliary functions.

Each class must be considered in detail and its effects upon automating the work station identified. This is complicated further because they are not necessarily independent. The material must be considered with regard to two subsets of properties:

(a) Handling; and

(b) Inspection.

Typical properties which must be considered include the material size, shape, and mass, the geometry of the transfer path, the accuracy of placement of the material, and the rate of transfer. Inspection involves ensuring that machining operations have occurred as required, critical tolerances are being maintained, and so on.

The physical environment surrounding the work station may increase the desire to automate as well as constrain automation equipment. For example, hot or wet conditions are unsuited to human operators, whilst explosive or electrically noisy environments limit use of electronic control systems. Industrial robots are designed with specified performance capacities. For example, the mass they can manipulate is specified between defined limits, speed of transfer, and accuracy of placement are typical bounded variables used to describe robot capacity. By specifying relevant properties of the work task, material, and physical environment, the designer aims to select an appropriate robot.

(4) Any robot possessing sufficient ability to perform the handling task demanded of it is a possible solution. As in the previous case studies, the designer is required to optimise his choice of solution according to some specified criterion; the criterion in this case is cost.

(5) To produce a design requires a sequence of mappings to transform problem description variables into robot description variables. Initially the design mapping needs to consider two classes of variables: geometric and non-geometric. Geometric variables describe geometric features of the work place and constrain the paths along which material can be transferred. The shape of the transfer path determines the set of robot articulations and its position at the work station. Non-geometric variables are those describing characteristics such as load, positioning accuracy, and rate of transfer or cycle time. These variables are used to directly specify robot abilities such as load capacity, positioning accuracy, speed of arm movements and so on.

Physical property comparisons allow robots to be selected which have the capacity to perform the tasks demanded. Each such robot can be regarded as a physically feasible solution. However, an optimal solution is required which necessitates selecting that solution which maximises performance. Performance is judged upon such factors as economics, maintainability, reliability, environmental influences, operational factors, and subjective factors.

In summary, any design scheme must identify the physical demands of the work place that the robot must satisfy, and select those having the necessary abilities. It then selects from this set that robot which maximises performance.

(6) To obtain a set of variables for use as a data base, the authors examined about 1000 work places in over 30 companies, selecting those variables which were relevant to automation. Establishing a description of industrial robots involved examining over 200 different models resulting in a data base comprising 80 variables.

Having obtained this data base, the next task involved determining the mapping between description variables, which comprised four stages:

(a) Matching non-geometric properties.

(b) Matching some selected geometric properties.

(c) Matching detailed geometric properties.

(d) Calculating robot performance.

The program begins by assuming all robots whose properties are known are candidates for selection, therefore the strategy is to eliminate as many as possible early in the selection procedure. Non-geometric property comparisons are easily applied and therefore are used first to eliminate unsatisfactory candidates. The geometrical property tests are time-consuming because of the large number of checks which must be applied, therefore this selection is performed in two parts. The first part determines gross arm movements such as length of stroke and angles of rotation for each work element and eliminates all robots which cannot perform these. The second part determines the optimum robot position based upon minimum cycle time.

At this stage the computer can specify the set of robots capable of performing the work task, their locations and orientations at the work station, and their optimum position. If more than one robot is suitable, a performance measure is determined for each, based upon the following criteria:

(a) Amount of investment.

(b) Operating expenses.

(c) Cost of maintenance.

(d) Cycle time.

(e) Service availability.

(f) Reliability.

(g) Operational comfort.

(h) Environmental factors.

(i) Quantifiable subjective influences.

Physically feasible robots are listed in order of their performance ratings. An outline of the selection procedure is given in Fig. 6.4.

6.6 A Generalised Problem Situation Susceptible to Computer Aid.

Four case studies have been examined where computers have provided useful aid to designers. Each case study was chosen on the basis of a marked similarity between the form of the problem and the problem situation facing handling system designers. This similarity exists between the structure of the problem and its solution, and the method of generating a solution from the problem description.

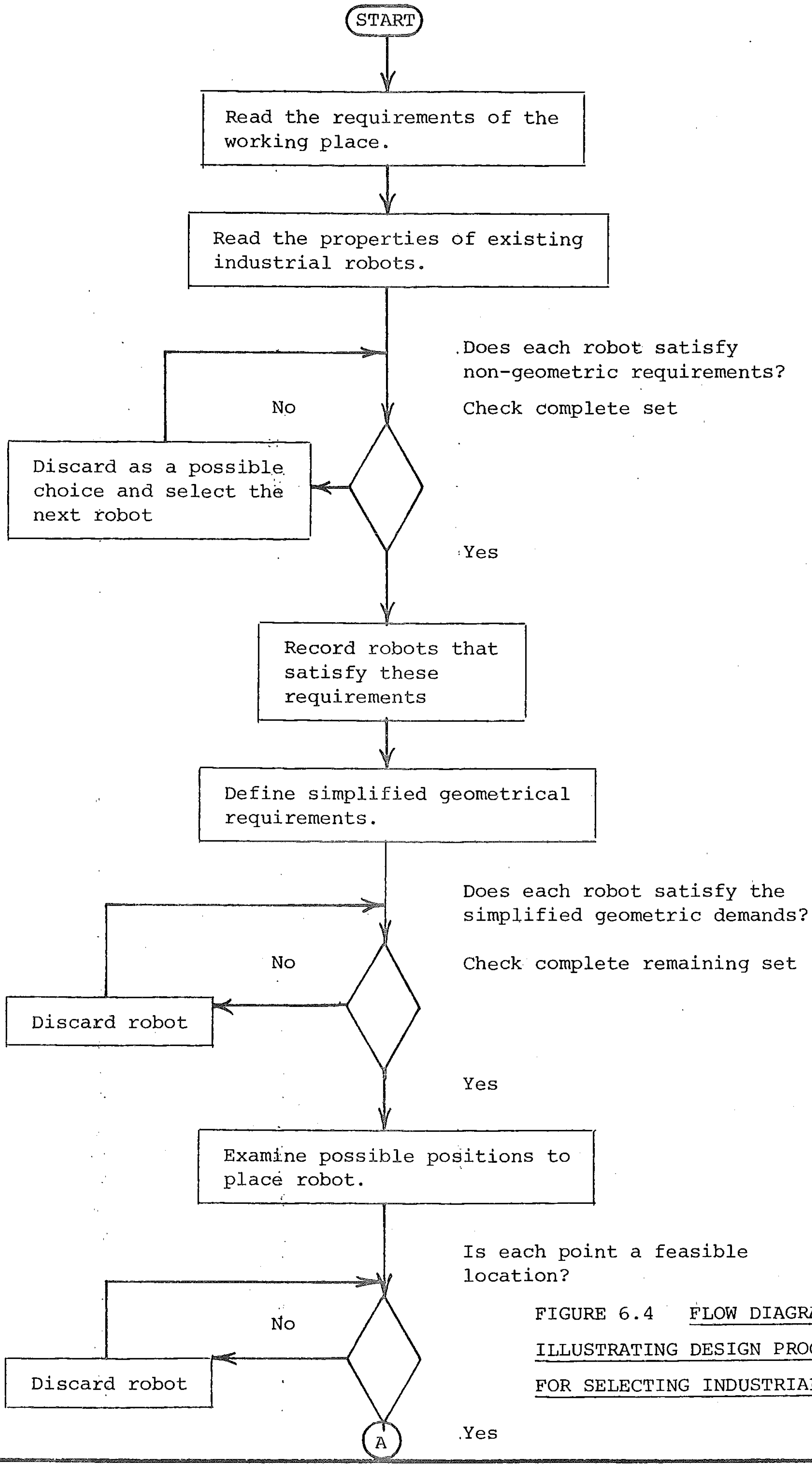


FIGURE 6.4 FLOW DIAGRAM ILLUSTRATING DESIGN PROCEDURE FOR SELECTING INDUSTRIAL ROBOTS

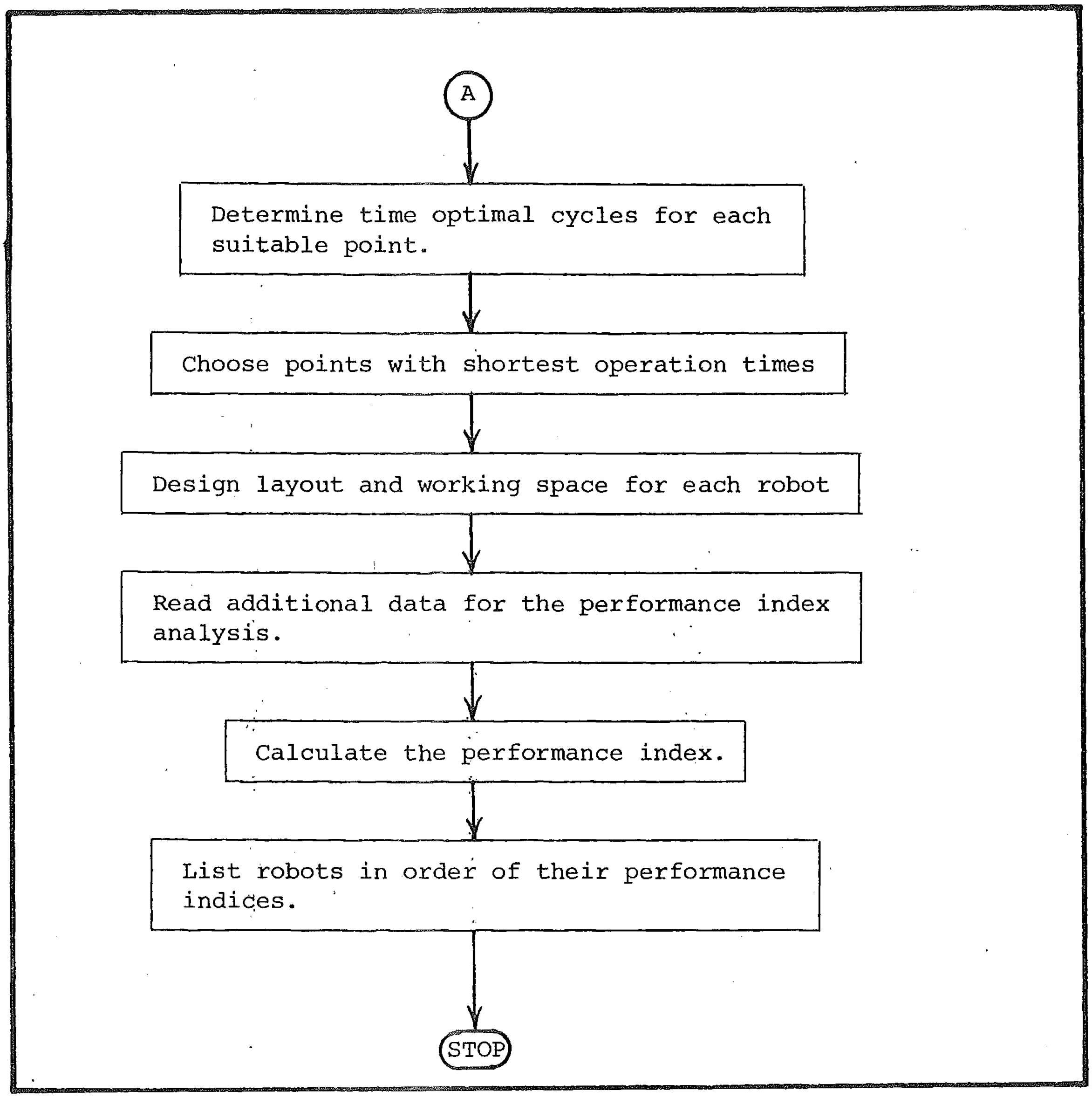


FIGURE 6.4 (Continued)

Two characteristics are fundamental to the design situation if it represents a problem to the designer: dissatisfaction and doubt. In each case study examined the designer was dissatisfied with a proposed or existing system. His dissatisfaction arose from factors related to economics and/or human safety. Furthermore, the designer was doubtful about how to make a choice which would change the system and remove his dissatisfaction. Experienced designers were unaware of procedures for obtaining a solution, and in each case the manual implementation of these procedures proved time-consuming and routine. Because experienced designers were required, the time spent designing a solution was expensive. In addition to cost of design time, it is important to include cost of a design error. In each example such an error is expensive and in the first case study, dangerous. A major source of error occurs in the calculation of relationships between problem and solution descriptions. Case Study One for example, requires many mathematical relations to be evaluated any one of which can generate an error. Apart from selecting a technically feasible solution, it was also necessary to select an optimum solution. Finally, each case study represented a class of design problems which were recurrent; problems in Case Study Two, for instance, occurred daily. In summary, the motivation to develop a computer-aided design procedure was provided by design cost, cost of errors, desire to obtain an optimum solution, and the routine nature of the design task. If a design situation possesses these characteristics it may well benefit from computer aid.

The next noteworthy characteristic of each case study was that a class of design problems could be defined by a closed set of properties describing objects and events. A particular problem being defined by a unique set of these properties. Similarly, a closed set of objects and events can comprise a class of solutions from which one is chosen. The task of assigning values to these properties is performed by the user, and as such, demands two abilities. Firstly, he must possess the ability to recognise when a particular problem is a member of the class for which the computer routine was developed, and secondly, the ability to assign values to properties required by the program. To aid the user in coding a problem, standard data sheets are provided. In Case Study One, a data sheet was provided in which the user entered the appropriate values to all properties. In Case Study Two, it was not always necessary to encode all properties, for example, if a chamfer was present it was encoded on a standard form; if however, there were no grooves, then the groove description code was ignored. Wherever the user was required to exercise his discretion, the computer routine contained an elaborate procedure for checking both the completeness and the logical structure of input data.

Wherever a problem and solution pair could be defined by closed sets of properties, the method of matching a solution to a specified problem can be envisaged as a mapping between discrete sets of properties. These mappings are not necessarily simple one-to-one correspondences between elements of the problem and solution sets. The case studies presented indicate that more complex mappings are required. Complexity arises for example, when objects comprising the solution set are not functionally or structurally independent. Therefore the selection strategy must consider compatibility relations between objects. Case Study Three provides a good example of selecting cutting tools using interrelated properties. Where compatibility relations exist, iterative selection routines are used to adjust each dependent property, thereby obtaining a suitable compromise. The first three case studies include iterative routines to produce physically feasible solutions. To optimise the solution meant using additional criteria such as cost, rate of manufacture, safety, and so on. Quantifying optimisation criteria for each feasible solution and comparing solutions according to such criteria often required repetitive calculation, as exemplified by the selection of optimal machining sequences in Case Study Three.

In each case study examined, logical design processes were used in the creative phase which accomplished the same result as intuitive processes used by the human designer. During evaluation none of these case studies required intuitive processes or subjective assessments to be made by the computer.

CHAPTER SEVEN

AN ANALYSIS OF CLOSED-SET DESIGN PROCESSES

7.1 Introduction

Chapter Six identified three important characteristics of design problems for which computers had successfully provided solutions:

(1) A class of problems could be specified by a closed set of measurable properties. An individual problem being specified by a subset of these properties.

(2) A class of solutions to these problems could be defined by a closed set of measurable properties. An individual solution being defined by a subset of these properties.

(3) A set of relationships between properties contained in the problem and solution sets could be identified and placed in a logical sequence. These relationships could be evaluated objectively.

Identifying sets of properties and logical relationships between them involved examination of several design examples. Researchers found discovery of the design process a major task. The difficulty of this task appears to depend upon the number of properties necessary to describe a class of problems and their solutions as well as the number of constraints upon their interrelationships.

A formal analysis to determine the effect of numbers of properties on development of a logical design process, the role of constraints in the design process, and limits upon the method of developing a closed-set design process is provided in this chapter.

7.2 Closed-Set Design Processes

Problem P_1 (figure 7.1) is examined in conjunction with its solution, the set of properties (p_1, p_2, p_3) are judged to be necessary and sufficient to describe the problem whose solution is defined by the property set S_1 given by (s_1, s_2). The mapping relating P_1 to S_1 is determined and denoted by m_1. A second problem P_2 of the same class is studied with its solution S_2 and the relevant sets of properties given by $(p_2, p_4, p_5, p_6, p_7)$ and (s_2, s_3, s_4, s_5) respectively. The mapping between these sets is denoted by m_2. This procedure continues until comprehensive sets of properties π and Σ are obtained, defining classes of problems and solutions together with a set of mappings M capable of transforming problem description properties into solution description properties.

Defining these sets formally, let a class of problems be defined by a set π of n properties p, such that

$$\pi = \{p_1, p_2, p_3, \ldots, p_n\}$$

Each element p of π may assume a numerical value, that is to every p there corresponds a dense denumerable infinite set $\langle x \rangle$ equivalent to the set of rational numbers in natural order of closed interval $\langle 0,1 \rangle$.

If for every problem definable in π there exists a unique solution, then a solution set Σ may be defined. Let Σ represent the set of m properties s, that is

$$\Sigma = \{s_1, s_2, s_3, \ldots, s_m\}$$

and to every element s of Σ there corresponds a dense denumerable infinite set $\langle y \rangle$ equivalent to the set of rational numbers in natural order of closed interval $\langle 0,1 \rangle$.

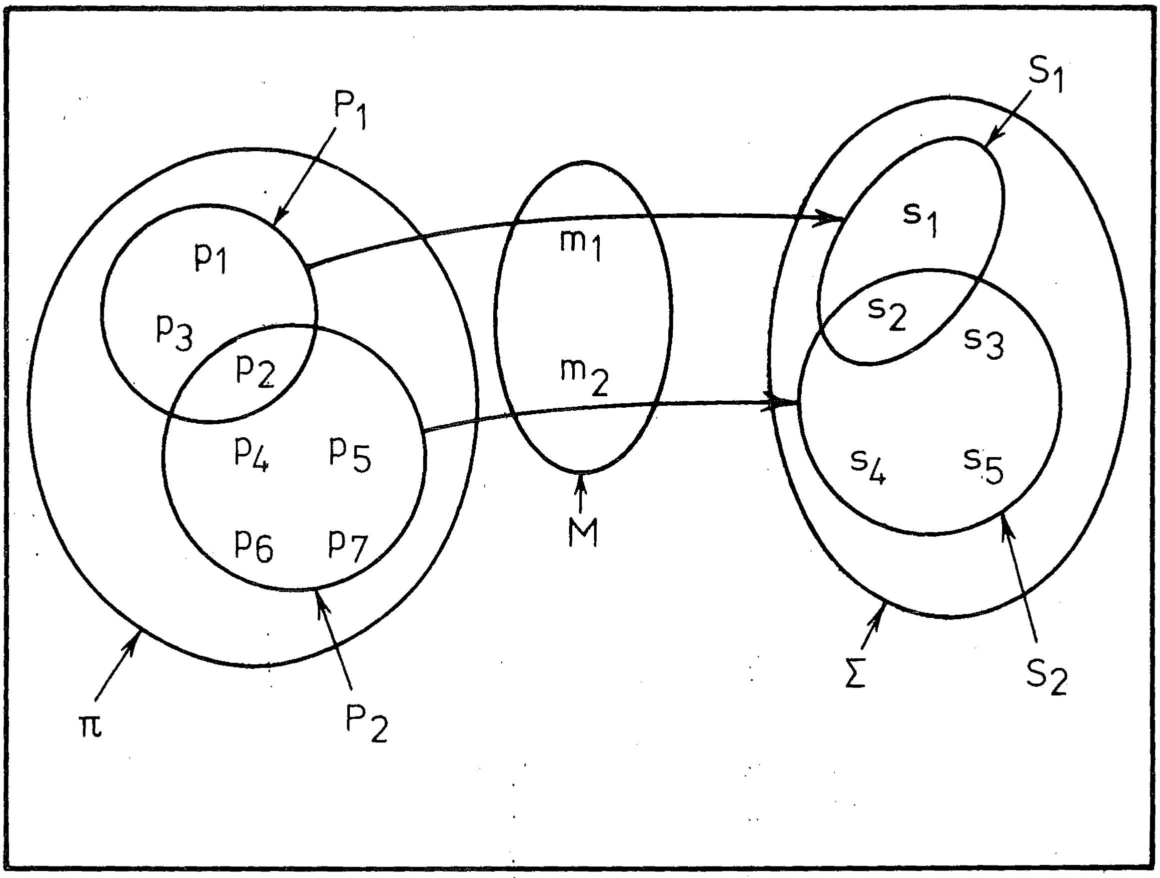


FIG 7·1 THE CLOSED-SET DESIGN SYSTEM

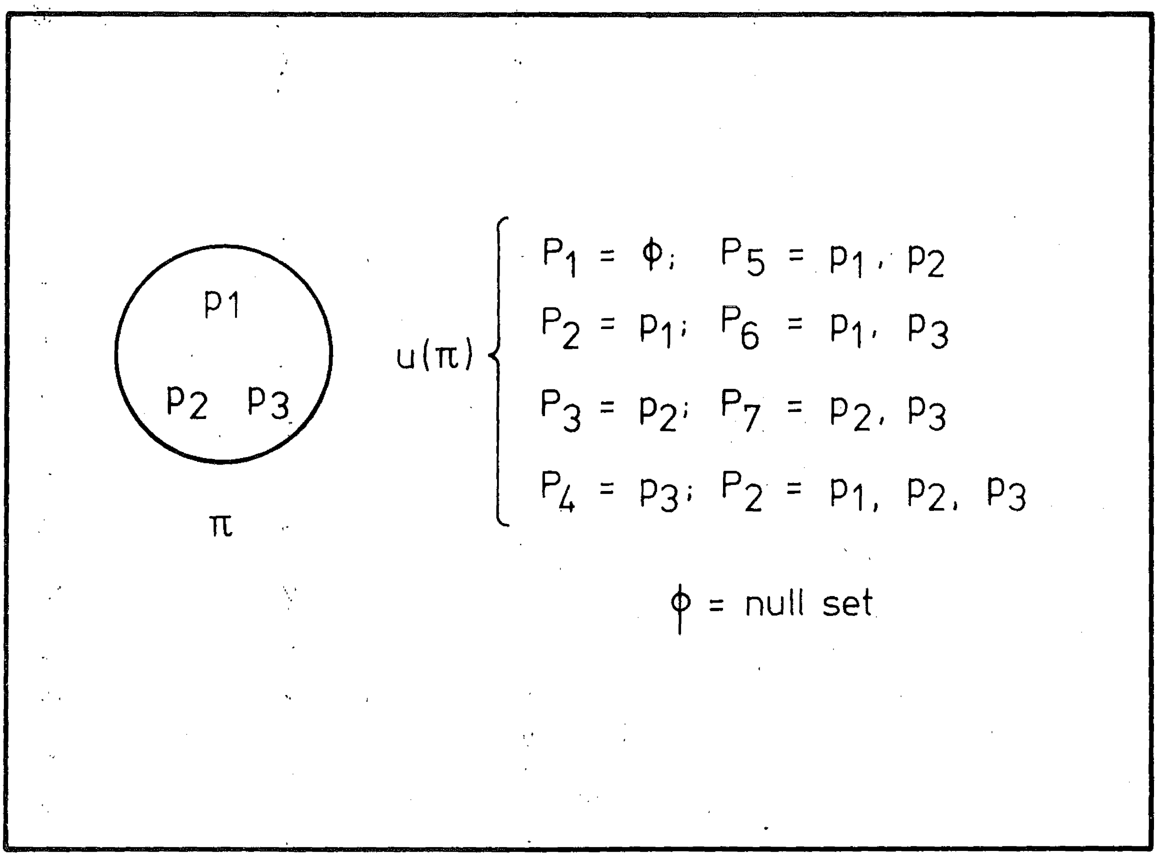


FIG. 7·2. PROBLEMS DEFINABLE FROM A SET OF THREE PROPERTIES.

For each problem-solution pair a mapping m is obtained. Each such mapping can be combined to form a general design process defined by the set M of mappings m, that is

$$M = \{m_1, m_2, m_3, \ldots, m_\ell\}$$

for ℓ distinct mappings.

Each mapping m represents a set of relations between individual properties or groups of properties, an important class of which are functional relations. These are of three types:

(1) Cause-effect.

(2) Producer-product.

(3) Correlation.

Cause-effect relations are deterministic and commonly used in the case studies examined. For example in Case Study Two specification of the set of properties defining an internal thread (type, diameter, and length) was both necessary and sufficient to select a tap as a suitable cutting tool. Producer-product relations are probabilistic or non-deterministic, for example tool life is a function of depth of cut, feed rate and material, varying statistically as the values of each variable.
Correlation is a much weaker relationship than either of the foregoing, and allows a measure of the tendency of variables to change together or not to change together. No examples of correlation were used in the case studies examined.

Closed set design processes are developed by choosing a sample of problems and their solutions which are representative of a problem-solution class. From this sample the property sets π and Σ are constructed. Selecting a sample raises two questions:

(1) How many observations should be taken? This is a question of sample size.

(2) Which particular problem-solution pairs should be examined? This is a question of sampling design.

With respect to the first query(1), the sets π, Σ, and M may be envisaged as a pattern of properties and relationships. Each of the case studies examined represent very complex patterns comprising large numbers of properties and relationships. The number of samples required to recognise a pattern will depend upon the researcher's pattern recognition ability and the pattern's complexity. Little need be said about a person's ability to recognise patterns except that each case study examined required a high intellectual ability to develop a satisfactory design process. The complexity of a pattern is dependent upon the number of its properties and relations. The more complex the pattern the larger the sample is likely to be.

The second question(2) introduces the problem of bounding the class of design problems which the design process is intended to solve. This requires a clear definition of the problems which are to be included. Development of a design process in practice is limited by availability of case studies, and so evolves as valid errors and exceptions arise; any problem-solution pair contributing a novel addition to the design process must be included in the sample.

Consider how many unique problems can be solved by a pattern of sets π, Σ, and M. The number is important because the worth of a computer aided design process lies in its ability to solve many different problems. Using the same notation as before, a problem P_i is defined as any set of elements p of π where

$$P_i = \{p_\alpha, p_\beta, p_\gamma, \ldots, p_\nu\}$$

of cardinality $\leqslant n$, then the extreme upper bound on the number of unique problems is given by the set of all subsets of π, namely $u(\pi)$, where

$$u(\pi) = \{P_1, P_2, P_3, \ldots, P_{2^n}\}$$

of cardinality 2^n.

Figure 7.2 represents a set containing three properties (p_1, p_2, p_3). Each unique problem is identified in the set $u(\pi)$, which includes the case of "no problem" for completeness.

For each problem P_i $(1 \leqslant i \leqslant 2^n)$ there may exist a unique solution S_j given by the set

$$S_j = \{s_\alpha, s_\beta, s_\gamma, \ldots, s_\mu\}$$

of cardinality $\leqslant m$, and S_j is a member of the power set

$$u(\Sigma) = \{S_1, S_2, S_3, \ldots, S_{2^m}\}$$

For every problem P_i there is not necessarily a solution S_j. The case may arise where a problem is insoluble or no adequate solution can be obtained from $u(\Sigma)$, therefore $n \geqslant m$.

Since a mapping m can select one solution to a problem (providing a solution exists), then m must contain all necessary constraints including optimising routines to select one member from the solution set $u(\Sigma)$. The sets π and Σ can identify 2^n and 2^m unique problems and solutions respectively, and even small values of n and m create a large number of possible problems and solutions. The number of elements of M is given by the number of ways of interconnecting $u(\pi)$ to $u(\Sigma)$. An extreme upper bound is given by the expression

$$(2^{2^n})^{2^m}$$

a function of the number of properties in the problem and solution description sets.

Figure 7.3 illustrates the derivation of this expression. Consider two sets of properties π and Σ containing just two properties each, therefore each set can specify four unique problems (P_1, P_2, P_3, P_4) and solutions (S_1, S_2, S_3, S_4) respectively. Solution, S_2, say may be related to any problem, thus the total number of states in the mapping may be determined. If the existence of a mapping is indicated by a "1" and non-existence by a "0" then Figure 7.4 indicates the possible states. This system has sixteen distinguishable states when just one possible solution is considered, but there are four possible solutions each capable of generating sixteen patterns in the design process. The interaction of the problem sets $u(\pi)$ and solution set $u(\Sigma)$ produces

$$(2^{2^2})^{2^2}$$

$$= 16^4 \text{ possible mapping patterns.}$$

The task of developing a design process is the same as selecting a subset of mappings from the total possible. Even for small values of n and m the number of possible mappings becomes large making an exhaustive search impracticable. Consider Case Study One as an example. Any engine-load system may be solved by choosing one main flywheel from five, one tail flywheel from five, one damper from six, and one driveshaft from five. The total number of unique solutions

$$= 750.$$

The maximum number of unique problems solvable by this set equals 750, and the number of possible design processes

$$= (2^{750})^{750}$$

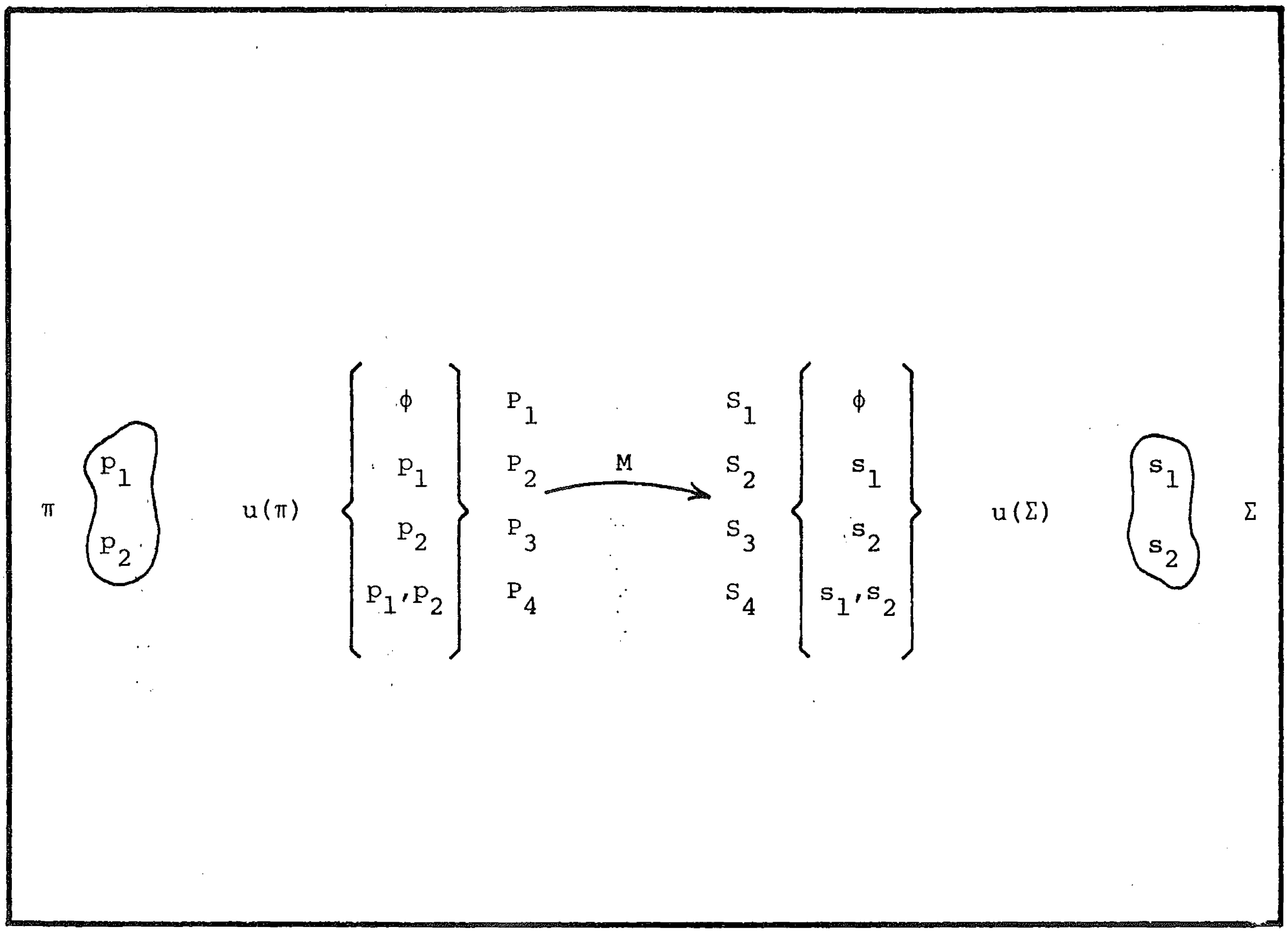


FIGURE 7.3 PROBLEMS AND SOLUTIONS POSSIBLE FROM TWO PROPERTIES

S mapped from problem - P_1 P_2 P_3 P_4

Mapping	P_1	P_2	P_3	P_4
1	0	0	0	0
2	0	0	0	1
3	0	0	1	0
4	0	0	1	1
5	0	1	0	0
6	0	1	0	1
7	0	1	1	0
8	0	1	1	1
9	1	0	0	0
10	1	0	0	1
11	1	0	1	0
12	1	0	1	1
13	1	1	0	0
14	1	1	0	1
15	1	1	1	0
16	1	1	1	1

Example:

S_1 under mapping 6 may be a solution to problems P_2 and P_4.

FIGURE 7.4 MAPPINGS POSSIBLE FROM FOUR PROBLEMS TO ONE SOLUTION

Developing a design process by exhaustive search is clearly impracticable for other than highly constrained problem situations.

The preceding analysis assumes that elements of π and Σ are independent and that any combination of them represents a possible problem or solution. Most of these combinations will never arise; they simply do not occur in reality, (20). Constraints and determinants exist which limit the combinations possible. Constraints are fixed relations and cannot be broken while determinants are man-made and may be broken at some risk.

Cause-effect relations provide constraints. A typical class being the scientific laws such as Newton's laws of motion, the gas laws, laws relating to generation and supply of electricity, laws relating to chemical change, and so on. The motion of a spring-mass system is constrained to a fixed path described by Newton's laws, as are velocity and acceleration of the mass at each point in the path. Thermodynamic laws explain the behaviour of a gas as it passes through a turbine where only certain changes in state are possible.

Producer-product relations also provide constraints. They predict, in a measurable way, the probability of an interaction between objects or events or both. Thus the probability of a cutting tool failing within a fixed time period will depend upon feed rate, depth of cut, and material properties.

Correlations although weak relations, may be used as constraints.

Social laws, moral and aesthetic values are determinants in a design situation. They specify desirable limits on relationships. For example labour awards limit the actions a manager may take, but he may go beyond these limits if he believes the penalty incurred is justified.

To develop an automated design process a person must possess sufficient knowledge and understanding of the design situation to enable him to identify essential properties of both problem and solution as well as relations between them. He must know how to solve a problem and understand the effect of changes in the environment on the problem situation. To gain an understanding of a complex design situation, such as those examined in the previous chapter, may take a considerable time because he is unable to operate intuitively. He must know how to develop a logical model of the design process.

CHAPTER EIGHT

THE HANDLING SYSTEM, THE ORGANISATION, AND DESIGN

8.1 Introduction

The concept of a material handling situation together with classes of properties necessary to describe a material handling activity were introduced in Chapter Three. Material handling activities do not occur in isolation but rather as one class of activities forming part of total activities performed by a larger system, such as an industrial organisation. Being part of an organisation the handling system interacts with other parts such as management, production, and maintenance to produce the overall objective of the whole. This interaction produces constraints and determinants on material handling activities which must be considered by the handling system designer.

The purpose of this chapter is to develop a model of a material handling system within the context of an industrial organisation which illustrates information transfers necessary to maintain control within the organisation.

A planning activity is required to allocate components and resources of an existing handling system to a set of handling activities. For a given set of handling activities, planners must determine alternatives available, assess the ability of each alternative to produce the desired outcomes, select the best alternative, and implement the plan. Information required to produce a plan is examined for the steady state case, where handling abilities of an existing system are sufficient to perform the handling activities.

The dynamic case involves changing components of the handling system and therefore requires a design activity. Relationships between handling and other organisational activities such as management, production, and maintenance, are examined to identify their effects upon design.

Finally the need to quantify measures of performance for the design are examined.

8.2 Regulating a Material Handling System

Regulation is concerned with varying the state of a system to produce a specified outcome under changing environmental conditions. Regulating a material handling system involves assigning components of an existing system to perform handling activities.

Figure 8.1 illustrates interactions between a material handling system and its environment. Handling activities occurring in the environment are accepted by the handling system which must attempt to assign equipment to perform them. Thus the function of the material handling system within an organisation is to provide the means necessary to transfer material for the organisation between specified points in space and time.

Charged with this function the handling system must comprise a regulator to assign equipment. Therefore the handling system comprises two functional classes of components, those concerned with regulating and those concerned with performing work. The regulating component is an information processing activity which accepts handling tasks, assigns items or groups of handling equipment and resources, and monitors how well they perform handling activities, while work performing components are items of handling equipment such as conveyors, cranes, trucks and the like.

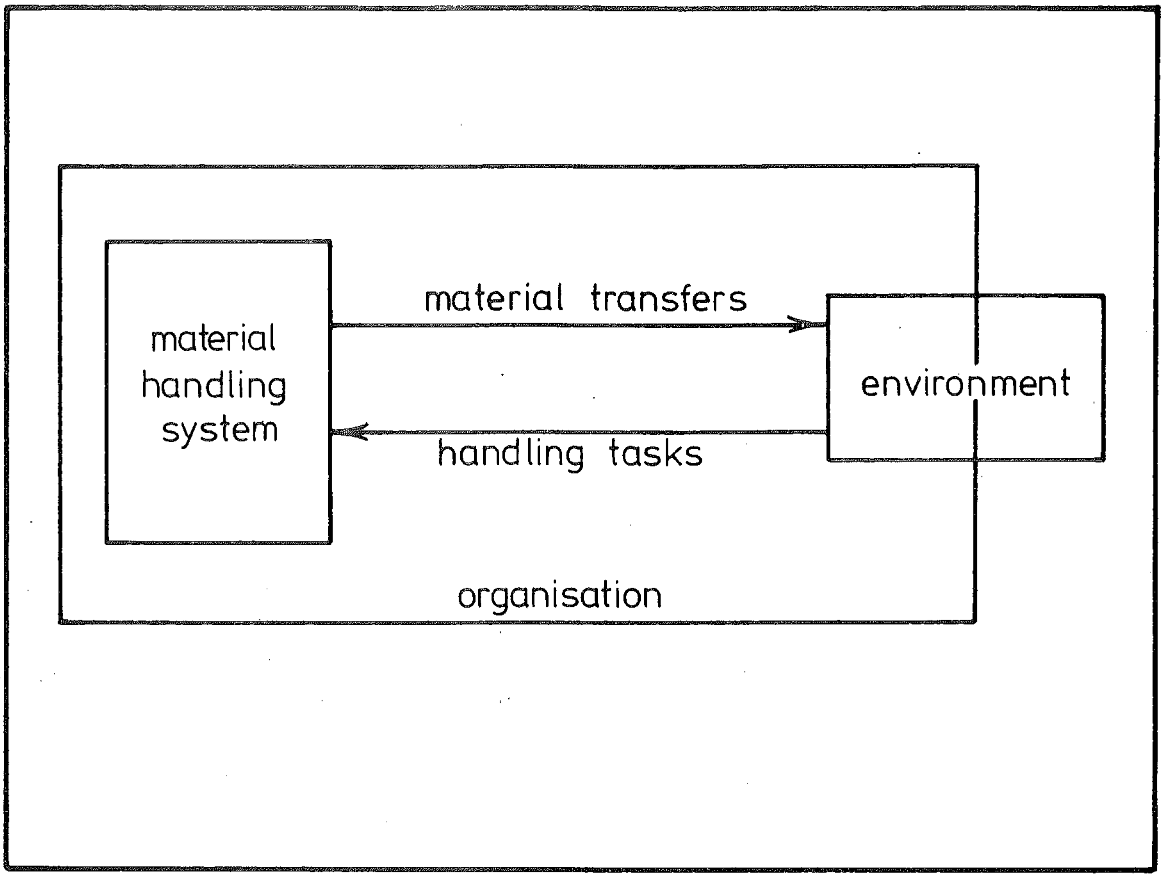


FIG. 8·1. THE HANDLING SYSTEM AND ITS ENVIRONMENT WITHIN AN ORGANISATION.

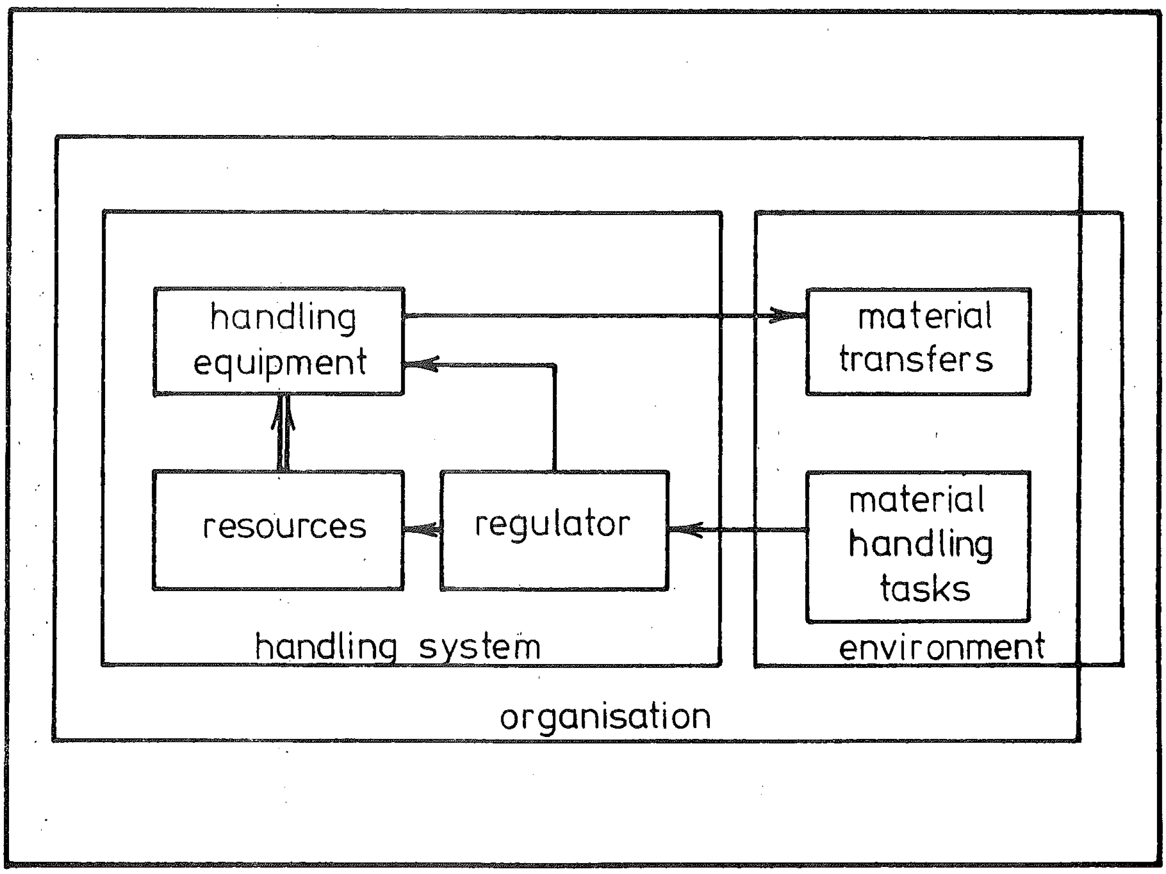


FIG. 8·2. THE COMPONENTS AND RESOURCES OF THE HANDLING SYSTEM.

Resources necessary to operate a handling system can be measured in terms of money, manhours, and energy. The regulator must be able to change resources and use them to best advantage of the system by altering their allocation.

Figure 8.2 illustrates these components and their interactions together with interactions between the handling system and its environment, part of which lies within the organisation and part without. This model represents information transfers necessary to maintain a steady state interaction between handling system and environment, thus ensuring that over a period of time handling activities which must be performed, are performed. If this were not so an accumulation of unperformed handling activities would occur or the handling system would possess idle capacity. Thus the term "steady state" refers to the components of the handling system remaining constant with time. The state of a handling system may remain steady as long as handling tasks lie within its capability.

The function of the regulator in the steady state condition was identified as assigning handling equipment and resources to perform handling activities. This involves monitoring the environment, choosing equipment and resources from the handling system to achieve a specified outcome and checking to see how effectively the choice produced the desired outcome. For example a production machine may need to be supplied with raw materials, the foreman instructs a forklift operator to transfer a pallet of material to the machine at a specified time, the forklift operator performs his task and the foreman checks to ensure the material was transferred as he instructed. In making his selection of a forklift truck the foreman must scan the handling equipment available and choose a feasible combination. Ideally he should optimise his choice according to some criteria such as minimum cost.

Choosing handling equipment is observed to be an iterative procedure involving preparation of long term strategies and short term tactics. Preparation of strategies for assigning handling equipment must consider global allocation of equipment to perform all handling processes performed by the system, whereas preparation of tactics involves the details of allocating equipment to each handling activity. In the previous example the foreman selects the forklift on the basis of its capability to perform the handling activity, but in so doing he must consider other handling activities already assigned to it. If the forklift was committed to other activities the foreman would have to consider an alternative choice.

Monitoring the performance of handling equipment in performing handling activities controls the operation of the regulator, and improves regulation in the future. For example the foreman may learn that the forklift operator is often late performing any assigned task, therefore he will adjust his choice accordingly. Thus the regulator has two functions, firstly choosing equipment and resources to obtain a specified outcome and secondly appraising existing courses of action for their effectiveness. Consider each of these functions in detail.

The task of choosing a feasible combination of handling equipment to perform a handling activity is illustrated in Figure 8.3. Any environmentally influenced handling situation H_i is received by the regulator which attempts to select a handling procedure P_j from all possible procedures capable of producing the outcomes O_{ij}. Because the system has fixed handling capability there is a finite number of distinct choices available to the regulator.

When choosing handling equipment care is necessary to balance the capacity of each item to the capability of the system. The capability of the system is maximum achievement with existing resources presuming the

Handling Procedures

		P_1	P_2	P_3	...	P_j	...	P_m	
	H_1	O_{11}	O_{12}	O_{13}	...		...	O_{1m}	
	H_2	O_{21}	O_{22}	O_{23}	...		...	O_{2m}	
Handling Situations	H_3	⋮						⋮	Possible Outcomes
	H_i	⋮				O_{ij}		⋮	
	H_n	O_{n1}	O_{n2}	O_{n3}	...		...	O_{nm}	

FIGURE 8.3 EQUIPMENT SELECTION MECHANISM

system were competently managed. This capability is limited by the capacity of the parts of the system, therefore if the capacity of some parts exceeds the capability of the system then there must be other parts (bottle necks) which are actively restricting capability. Consider what is involved in balancing a handling system. The output of an item of equipment will vary with time according to a statistical distribution as illustrated in Figure 8.4. This distribution is skewed towards an upper limit c_o which represents the maximum designed output. It is skewed having its most probable output near its maximum. The range of acceptable output has a lower bound, below which it is not economically or legally feasible to operate. When several items of equipment are combined, each having its own independent performance distribution, the result is another distribution illustrated in Figure 8.5. The upper limit C_s is the capability of the system and represents the maximum feasible output of the system. The actual output O_A is affected by the output of the parts, and is bounded at the lower end by a lowest acceptable output. In choosing and allocating handling equipment and resources, care is needed to avoid bottlenecks or idle capacity.

The second function of the regulator was appraising its effectiveness. Performance measures are a function of actual system output, O_A, and the output necessary to satisfy the handling activity. Variables describing output of the system may vary over a range bounded by the lowest acceptable output and the system capability. Provided O_A lies between these bounds then regulation is acceptable, but this may vary with time. For example there may be a trend in O_A which is tending towards the lowest acceptable output. Therefore the regulator should monitor trends which can be used to forecast a change in handling procedures in the future. Trends may occur, for example, from an increase in downtime of handling equipment caused by wear.

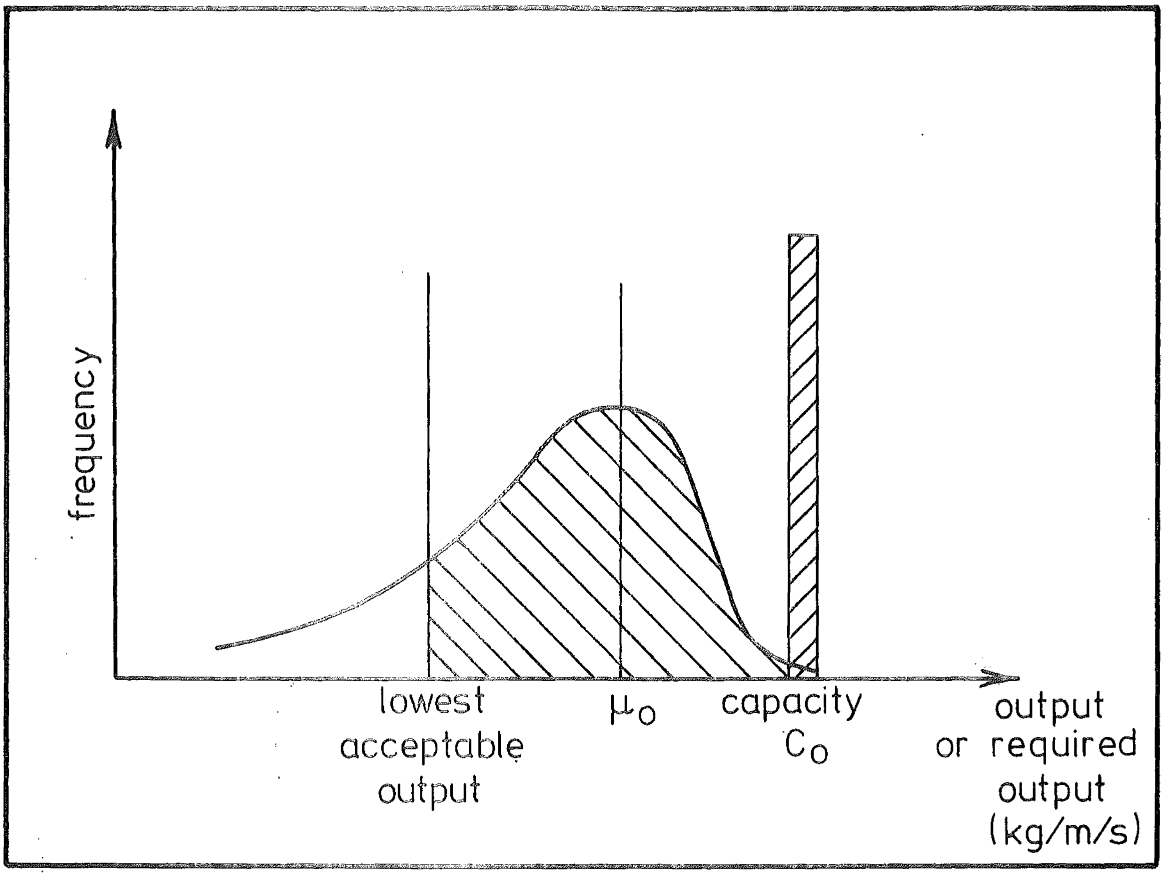


FIG. 8·4 THE VARIATION WITH TIME IN OUTPUT FOR AN ITEM OF HANDLING EQUIPMENT.

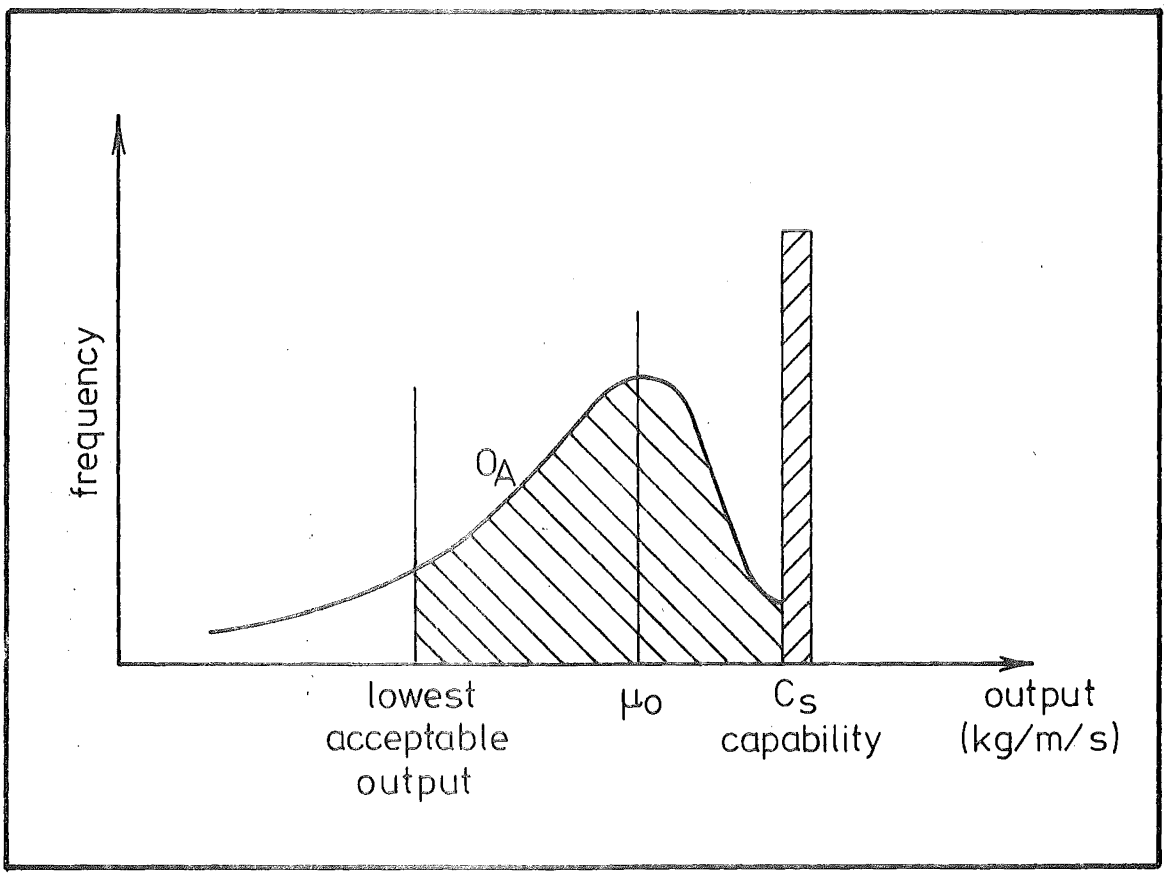


FIG. 8·5 THE VARIATION WITH TIME IN OUTPUT FOR A SYSTEM OF HANDLING EQUIPMENT.

Selecting handling procedures and monitoring their effectiveness requires another change in the model of Figure 8.2. This includes addition of two feedback loops, one to account for the iterative procedure for choosing a handling procedure, and the other to monitor the effectiveness of existing procedures and modify them when necessary. Figure 8.6 illustrates the final form of the model of a handling system under steady-state conditions.

8.3 Handling System Dynamics

This section is concerned with dynamic interactions between handling system and environment. Where no procedure which provides a performance greater than the lowest acceptable can be found for an existing handling system, then the system must be changed. Logically if a handling activity arises which is beyond current handling capabilities, two courses of action are available; either the system must create new handling ability or it must reject the activity.

In concept both courses can be included under the general heading of "adaptation".(6) Formally, a system is adaptive if, when there is a change in its environment and/or internal states which has reduced its efficiency in performing its function(s), it reacts or responds by changing its own state and/or that of its environment so as to increase its performance with respect to its functions.

Four types of adaptation are implicit in this definition.

(1) The handling system may react or respond to an external change by modifying the environment. For example the regulator may modify a handling activity such that it comes within existing handling ability.

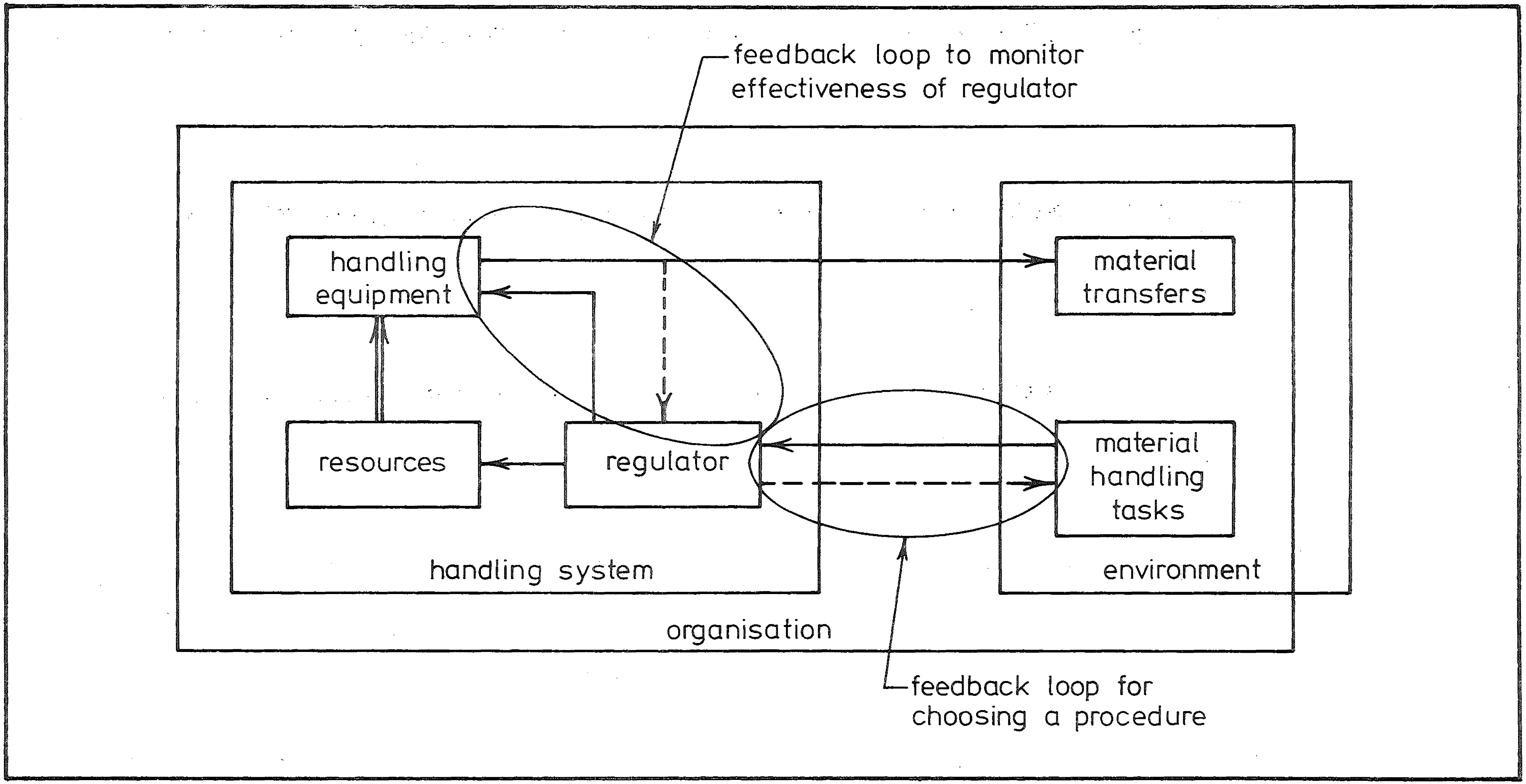


FIG. 8·6. HANDLING SYSTEM UNDER STEADY STATE CONDITIONS.

(2) The system may react or respond to an external change by self-modification. This involves changing handling ability by changing its structure, that is by designing a new handling system.

(3) The system may react or respond to an internal change by modifying its environment. For example a reduction in handling performance by persistent mechanical failure may convince management that some handling activities are not worth performing.

(4) The system may react or respond to an internal change by modifying itself. An example being the case where mechanical failure of handling equipment is modified by maintenance activities.

Each type of adaptive behaviour can be identified with functions performed within industrial organisations. Adaptive behaviour of types (1) and (3) involves changes in a manufacturing or processing function. Type (2) adaptation requires the facilities of a design function, while type (4) adaptation requires a maintenance function.

Organising these functions, processing, handling, maintenance and design, requires a management function. The model represented in Figure 8.6 can be extended to include these organisational components. This is illustrated in Figure 8.7.

This model does not attempt to provide an exhaustive list of organisational activities but rather provides a structure to demonstrate activities and their interactions which are important to material handling. It is based upon the cybernetic model developed by Beer(21) to identify the information transfers necessary to control an organisation.

Material handling activities arise in conjunction with manufacturing or processing activities. The handling needs are communicated to the handling system regulator which examines them and attempts to assign

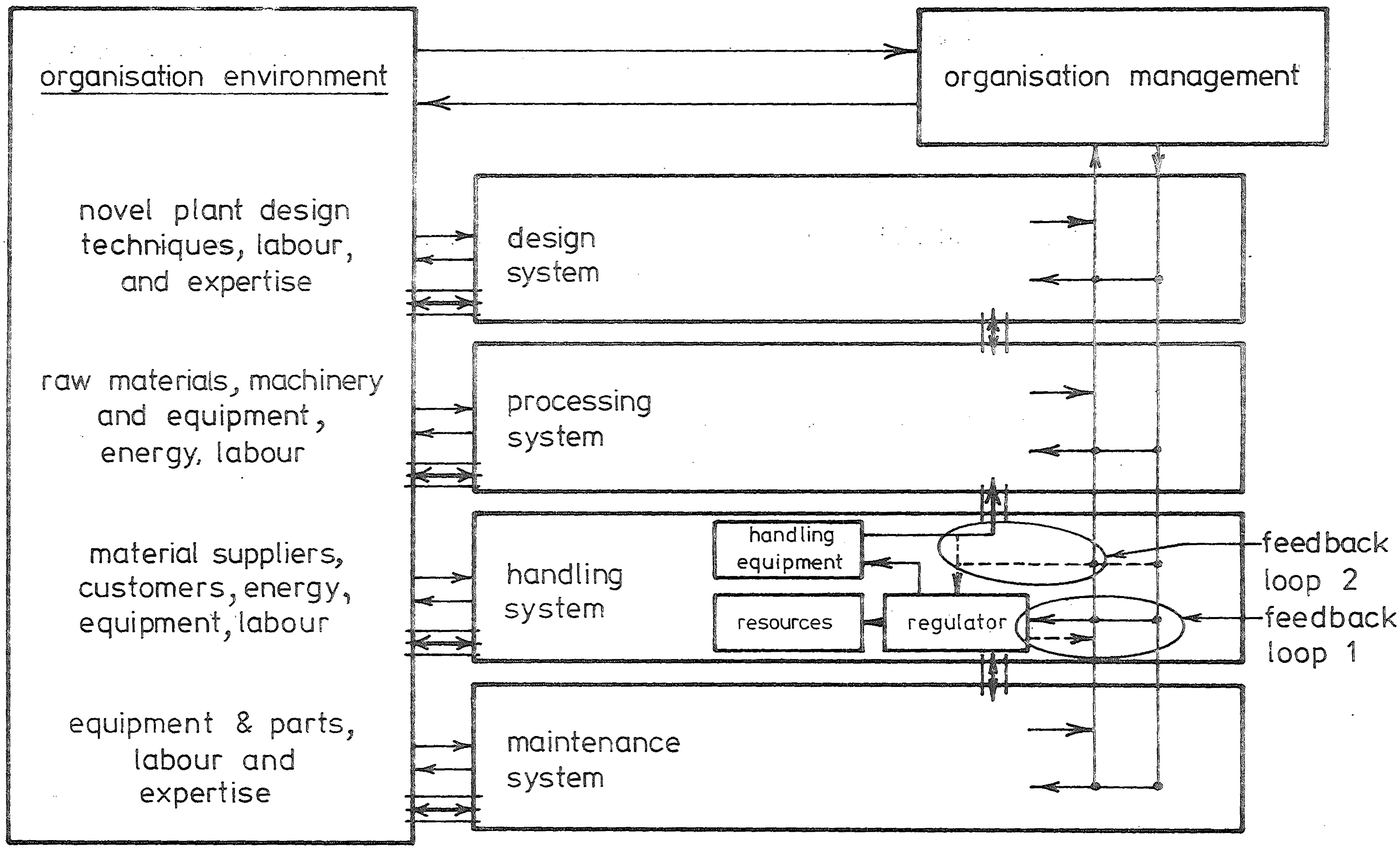


FIG 8.7 THE HANDLING ACTIVITY WITHIN AN ORGANISATION

handling equipment to perform them. Each handling activity may be modified to suit both handling and processing systems by the feedback loop 1 . Limits are placed upon modification to the handling activity by technological constraints of the processing system as well as by economic, legal, and other constraints and determinants specified by organisation management. Communication lines for this purpose are available to management.

If the regulator is unable to choose a procedure to perform a handling activity and is unable to modify that activity, it is necessary to design a change in the handling system. The designer needs information from the processing system describing the handling activity, from the handling system about its lack of ability, from management about limits on resources which can be expended to produce a design, and from the maintenance system about maintenance ability. Communication lines are provided in Figure 8.7.

Mechanical failure of handling equipment, must be communicated to the maintenance system whose function it is to repair the equipment. Processing and management systems need to be informed because the failure may require production rescheduling, informing customers of delays, implementation of contingency plans, and so on.

Within this structure management's purpose is twofold, firstly it must determine the objectives of the organisation, and secondly limits upon use of resources and acceptable performance standards required to achieve these objectives. In specifying both activities performed and standards of performance, management controls the organisation.

Included in Figure 8.7 are interactions of the organisation's components with its environment. The design system needs information on new handling equipment such as industrial robots for example, as well as new analytical and design techniques. Resources such as labour possessing design expertise are required from the environment. Processing and production systems rely upon a supply of raw materials, plant and equipment, labour and energy from the environment. The handling system derives its resources such as equipment, labour, and energy from the environment. Customer supply and delivery requirements influence handling methods. Maintenance systems obtain resources including equipment and spare parts, labour and expertise.

Figure 8.7 is essentially a diagram of information transfers, mass transfers are nevertheless important and are indicated by wide arrows between organisation components and between organisation and environment.

The dynamics of this structure depend upon quantification of its performance. The handling system designer is interested in how he can change a part of the organisation so that the change alters performance of the whole. To do this requires performance measures for the whole organisation and for the handling system. Because the organisation is a system comprising interacting components, the manner by which one component can be altered to benefit the whole is by no means obvious. If the designer has a suitable set of measures of the organisation's performance over a period of time, $[M]$, he now seeks to find a performance measure $[m_1]$, $[m_2]$, ..., $[m_h]$, ..., $[m_i]$ for each component which will have a certain relationship to $[M]$. Both $[M]$ and $[m_i]$ are column vectors of performance measures, and $[m_h]$ are performance measures ascribed to the handling system. Dimensionally $[m_h]$ may be expressed as; items or quantities of material/hr/move, cost/item/move, cost/hr/move, and so on.

There are at least three types of relationships between component performance measures $[M_i]$ and the organisation measure, $[M]$:

(1) $[M]$ is maximised if and only if every component measure $[m_i]$ is maximum, (providing each component is independent).

(2) A positive change in the value of $[m_i]$ produces a positive change in $[M]$ for at least some range of values of $[m_i]$.

(3) There exists a mathematical formula which expresses $[M]$ as a function of the $[m_i]$'s only, and the global maximum of this function exists.

The performance of an industrial manufacturing or processing organisation is commonly expressed in economic terms. The dimensions of these measures depend upon the objective of the decisionmaker. For example, shareholders are interested in surplus of income over expenditure; management are interested in the efficiency with which raw materials are converted to products, while technical staff may be interested in the efficiency with which a production machine utilises its energy input to produce its products. Material handling activities are regarded as direct costs which tend by their very existence to reduce performance of the organisation. Therefore an appropriate strategy is to eliminate handling activities so long as they do not reduce the performance of other activities such as processing and maintenance. Therefore an increase in handling system performance $[m_h]$ (decrease in costs) increases the organisation performance $[M]$ within a defined range of values of $[m_h]$. The designer must be aware of these limits.

Apparently the designer is presented with an extremely complex problem. Not only does he have the task of matching properties defining handling equipment to those defining the handling activity, but also he must consider the interactive nature of the organisation which brings with it additional constraints and determinants, and the need to optimise for the whole. This problem may be eased using the concept of separability. (13) (22). This means the designer, before introducing additional organisational complexities, can examine specific objectives, (related to handling) and it permits an adequate scanning of the alternatives, together with a reasonable evaluation of each within a technological framework.

Using the concept of separability design activities may possess the following structure. The designer takes the handling system to be separable as long as it "behaves properly", and redesigns it whenever it does not. The crucial point for the designer is whether he can recognise an unsatisfactory state without having to study the entire organisation in depth. This is equivalent to asking whether the design process is dependent upon prior states of the organisation, or merely upon a subclass of the components. If it is a function of the organisation then the designer needs to know or estimate properties of the whole organisation in order to judge how to change a part. The concept of separability enables the designer to regard the design process for handling systems as a function of the prior state only, or, at least within recognised bounds.

In summary, the designer retains familiarity with the components of the organisation, and when he detects an unsatisfactory change, he moves to modify that component. The approach is "incremental" in that the designer moves in steps which are invoked by a change in performance measures and are acceptable to organisation management. This is the mechanism normally experienced in industrial handling systems design.

The result of both designing and regulating activities is to produce a detailed structural specification of an adequate material handling system. To obtain this objective it has been shown necessary to consider technical, economic, legal, political, moral, and aesthetic constraints and determinants within the framework of an organisation. Technical aspects related to the material handling activity were identified in Chapter Three, while organisational aspects are identified in this chapter. The large number of possible variables and their interrelatedness creates a complex task for the designer when designing a handling system. A logical design procedure could significantly aid him in this task.

CONCLUSION TO PART ONE

A logical analysis of several existing industrial handling systems indicated that four principal factors interacted; (1) the material to be handled, (2) the transfer path along which the material is conveyed, (3) the handling equipment, and (4) the environment of the handling system. The environment was considered in two parts; (1) objects or events which interact with structural properties of the material, transfer path, or equipment and (2) the socio-technical system of which the handling system is a part.

Handling activities may be described as a sequence of actions which produce a change in location and/or orientation of the material in space and time. They are produced by handling equipment possessing five essential functional components; (1) a containment or grasping component, (2) a structure supporting the containment component, (3) a prime mover, (4) a power transmission component, and (5) a controller.

The design process may be defined as the production of a message describing essential features of a new object or system so that it can be produced. To produce a design the designer must possess a method together with adequate design information. Given sufficient motivation to design, design processes appear to proceed by iterative processes of creating and evaluating until a satisfactory solution is reached. A message is prepared describing this solution.

As the ultimate aim of this design process is a detailed structural specification of an adequate materials handling system, the designer must identify essential properties of the components of the handling situation, he must select suitable combinations of equipment, and then choose the best combination. Identification of essential properties and selection of adequate solutions is a creative task.

A general design strategy was proposed involving four stages:

(1) Identification of general functions of the handling system.

(2) Identification of specific functions to be performed by the handling system.

(3) Identification of general structural classes necessary to perform these functions.

(4) Identification of specific structural properties of items of equipment capable of performing these functions.

People appear to use two mental activities in creating a solution: thought and intuition. Thought processes are conscious processes used to manipulate the designer's mental model, while intuitive process are unconscious.

Evaluating the result of a creative process may be performed objectively or subjectively. Objective evaluation is on a clearly defined and measurable basis while subjective evaluation depends upon a person's feelings or on his untested beliefs. Four headings were proposed under which evaluations may be made; (1) on a scientific basis within established scientific truths or technical constraints, (2) on an economic/political basis, (3) on a moral/legal basis, or (4) on an aesthetic basis.

Based upon this understanding of design processes, four automated design processes were examined. In each case it was found that:

(i) In the creative phase the program was supplied with a memory of a finite range of acceptable components which it could assemble as proposed solutions according to given rules, that is, according to a logical choice process. Designers had previously intuited these proposed solutions. Researchers have found the discovery of a logical process to replace a designer's intuition a major task.

(ii) The proposed solutions of the creative phase were evaluated on a technical/scientific basis by procedures and criteria built into the program and ordered on an economic basis according to a clearly defined and agreed procedure.

Hence, as expected, although logical sequences were used which accomplished the same result as the intuitive process, none of these cases involved intuitive processes or subjective assessments.

If a computer is to be used to aid in designing a class of material handling systems, four criteria must be satisfied:

(i) A class of problems must be able to be described by a closed-set of measurable properties.

(ii) A class of possible solutions must be able to be described by a closed-set of measurable properties.

(iii) A set of relationships must be identified to match a solution to a given problem, and then ordered in a logical sequence.

(iv) The person developing the computer program must possess or gain adequate knowledge and understanding of essential variables and relationships involved in the design process. An exhaustive search for possible relationships between essential properties is unlikely to yield a design method.

PART TWO

A Logical Procedure for Designing Material Handling Systems

INTRODUCTION TO PART TWO

Part One examined four principal factors which were regarded as being fundamental to a study of applications of digital computers in designing material handling systems.

Part Two begins from this base and comprises two chapters.

Chapter Nine identifies a set of activities which are both necessary and sufficient to produce a design for a material handling system. These activities are placed into a logical sequence and combined with properties of handling systems identified in Part One. Necessity for creative abilities within this sequence is identified.

To illustrate application of this logical design procedure, Chapter Ten examines an actual handling system design situation. In addition, a comparison is made between the logical procedure and the intuitive procedure used by human designers, to identify advantages of using a logical procedure.

CHAPTER NINE

A LOGICAL APPROACH TO THE DESIGN OF MATERIAL HANDLING SYSTEMS

9.1 Introduction

Material handling system designers have no rigorous or logical procedures to lead them from a stated need to perform material transfers to the selection of satisfactory handling systems. They look for clues, make guesses, and reject alternatives in typically undefined ways.

The major objection to using undefined design methods is that they encourage aprioristic choices which rarely lead to optimal solutions, and may not even provide good solutions. The concept upon which aprioristic decisions are based in systems design is that of separability. That is, the designer believes he can separate one set of handling activities from the total handling process, and solve them as if they were independent. Unless the complete system is modelled such an assumption may not be justified.

The aim of this chapter is to develop a logical design system based upon Part One, together with general design rules and procedures taken from current handling system design literature.

Section 9.2 identifies a set of components and their interrelationships which are necessary and sufficient for a suitable design system.

Section 9.3 identifies a logical sequence for designing handling systems.

Finally section 9.4 identifies, for this design system, where creative ability requiring human intuition is necessary, and where purely logical procedures may be used.

9.2 A Systems Approach to a Design Process

A handling system design process can be envisaged as a design system, whose objective is to select feasible sets of handling equipment capable of performing specified handling processes, and then to select from those feasible that set which performs best within a client's set of values.

Apple (1) identifies a sequence of design activities performed by human designers. These are modified and placed into a set of components comprising a design system:

(1) Identify the handling activities.

(2) Collect data.

(3) Determine what data is relevant.

(4) Suggest classes of equipment which appear to be satisfactory.

(5) Suggest further limitations based upon design experience, principles of material handling, and so on.

(6) Select feasible handling systems.

(7) Evaluate performance of each system.

(8) Assign performance measures to each feasible system and order them.

(9) Recycle if no solution is sufficiently satisfactory.

Whether this is an exhaustive set of components for a design system is not obvious, nor is it clear whether suitable performance measures can be identified for each component such that an increase in the component measure increases the performance of the whole system. It does however provide a base from which to proceed.

Component one, identifying the handling activity(ies), is closely related to a processing or other activity which creates the need for handling. Therefore identifying handling tasks requires a model of material transfers necessary within a processing or manufacturing system. This model must express the output required from the handling system to satisfy production in terms of rates of material transfer, timing of transfers, and cost of the transfers. An improvement to existing handling systems is initiated by unsatisfactory performance measured by these variables. Both material and transfer path must be identified for each handling activity.

Collecting data to describe a handling activity involves examining the material and transfer path to identify their essential properties. These include any geometric, kinematic, mechanical, physical, or morphological property which will affect either the equipment selected or the environment within which the material transfer is performed.

In a complete design system it is essential to specify not only how to collect data, but also what data to collect. The central difficulty is identified in Chapter Three as the need for a relevance criterion without which the designer seems to be faced with an infinite set of properties any of which could be relevant to describing the handling task. There seems to be no purely logical criteria for deciding which properties to use, although there may be some economic criteria based upon cost and time for gathering these essential properties, as well as technological criteria based upon computer memory capacity and speed of accessing data. How can this difficulty be eased when the only real relevance criterion appears to be the inherent design? That is, when the final design is produced, those properties required to produce the design are those that are relevant. But this is a circular argument because the designer is not aware of the solution when he begins; it is a problem to him. This indicates the need for an iterative procedure which proposes a solution, evaluates it, and modifies the next proposal based upon what has been learned from the evaluation. It should be noted that component three is not separable from the others in the design system, especially not the fourth and sixth.

The fourth component poses the most serious challenge to developing a logical design process. Given a general description of a handling task, what kind of rules are necessary to move from this general description to a description of a specific class of handling equipment? Such a description identifies structural properties of material, transfer path and environment. It describes the function of the handling equipment required. What it does not do is identify a class of equipment which possesses this function. At this point, where there is a need for an intuitive leap from function into structure, discovering a logical procedure to provide a solution is a difficult task. In the case studies examined in Chapter Six, a class of objects possessing the necessary functions were identified and stored in memory which could be accessed by a set of logical relations given a description of the problem. In practice, the intuitive abilities of the human designer are required to satisfy this component.

The fifth component of the design system comprises a set of design rules and principles used by handling system designers. Such principles are not however specified rigorously but are expressed and used as "rules of thumb". Apple (1) and Immer (2) both identify principles such as "the unit load principle" which aids the designer to make a batch/continuous decision, "the safety principle" makes the designer aware of safe practice requirements, and so on. The problem at this stage is really of the following type: Given a set of design rules that have a high degree of implicit or explicit acceptance within handling system design practice, how does the designer become aware of these rules, and how does he select the appropriate rules to increase his power to discriminate between alternatives in the class of solutions selected by the fourth component? Interactions between components of the design system give no real guides to developing this fifth component. For example it would be possible to avoid steps four and five if the designer was willing to invest more time and effort into steps seven and eight. As in case study four (Chapter Six) the program begins with all possible solutions, aiming to eliminate each unacceptable alternative in order. The large number of alternatives in designing handling systems makes this approach unacceptable. Conversely, much more effort could be assigned to component four, where it may be possible to distinguish within the original data set only one feasible solution. This approach was tried for a range of handling equipment and proved unsuccessful. How much effort should be put into one or another phase is not clear, and furthermore it is not clear how human designers decide.

Component six distinguishes between individual items of equipment within a feasible class. The distinction is based upon capacities of items of equipment. That is component six has the purpose of balancing capacities of items of equipment to the capability of the system thereby avoiding excess workloads or idle capacity.

In summary, the function of the first six components is to identify handling tasks which need to be performed, properties necessary to describe each handling activity, select feasible classes of handling equipment capable of producing necessary actions, and selecting individual items of equipment which are compatible each to the other.

Components seven and eight are concerned with identifying suitable achievement measures for feasible alternatives chosen by the designer. Two classes of achievement measures are used by the design system; (1) measures to discriminate between feasible alternatives to select the best system for a handling process, (2) measures to determine changes in achievement of the system when it is operational. This allows management to assess when the intrinsic system should be changed.

Beer (21) identifies three separate measures of capacity and their ratios as illustrated in Figure 9.1: (1) Actuality, which is what the system actually achieves, (2) Capability, which is what could be achieved with existing resources if the system were managed competently, (3) potentiality, is what could be achieved if the shortcomings of the existing system were overcome by investigating the cause, and financing the redesign, redevelopment, production, and installation of improvements, within existing technological constraints.

Using Beer's measures for determining optimal combinations of handling equipment involves comparing the output which the system must be capable of (its capability) with the output the designer believes his design will produce (its expected actuality). The system is chosen whose expected actuality most closely approaches the required capability, that is, whose productivity most nearly approaches unity. While a handling system is operating measures concerned with ratios of actuality to capability, or productivity of an existing system, and with ratios of actuality to potentiality, or the performance of the system must be obtained. Such measures may be evaluated objectively or subjectively.

In practice measures possessing a cost dimension are commonly used, such as cost per item transferred per hour for objective criteria, while subjective measures on moral or aesthetic aspects are given scant regard.

Management may be interested in the achievement of the designer wherein suitable measures are obtained by examining the ratio of capability to potentiality, that is, latency of the designed system.

The ninth component of the design system provides a method for designer and client to re-examine the handling system where the client is dissatisfied with all alternatives proposed.

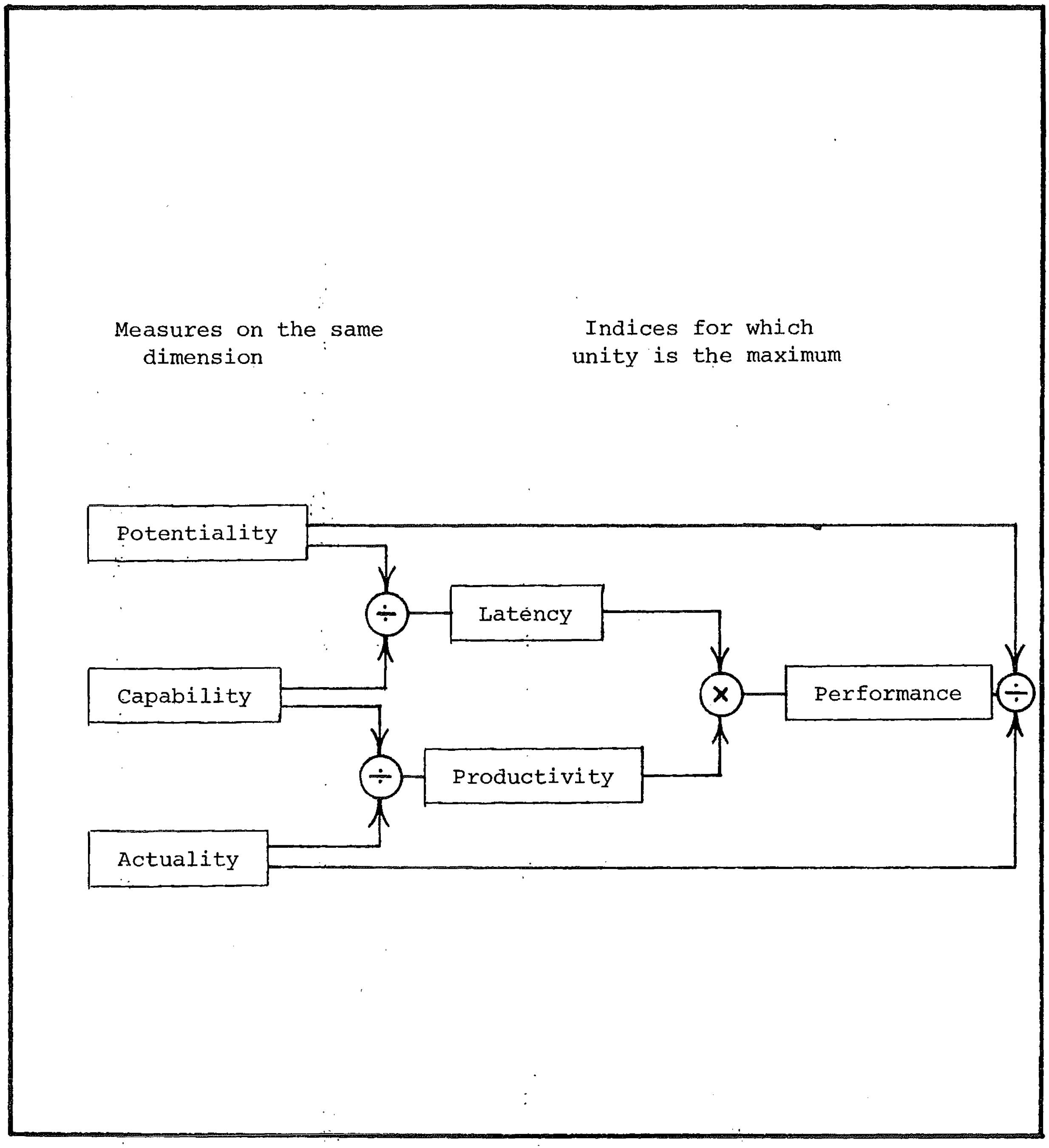


FIGURE 9.1 THREE MEASURES OF CAPACITY GENERATING THREE MEASURES OF ACHIEVEMENT.

Implementing the design is not part of the design system but is part of its environment. It involves transforming the designer's message (the design) into physical reality which may require a design change during implementation.

9.3 A Material Handling Design System

This section develops a logical sequence for applying the design components identified in the preceding section. The strategy is identified in Chapter Four. This begins with identification of general functions of the handling system; simply, what the handling system must do. To achieve these general functions it must perform particular handling activities; these are the specific functions the handling system must possess. Each handling activity can be described by a set of structural properties which must be identified. These properties are then used to select items of handling equipment. Initially only general structural classes of equipment need to be identified. These are then examined against practical requirements such as availability of equipment, compatibility between feasible alternatives, and the need for packaging material. Solutions are adjusted accordingly. Changes to the organisation caused by these solutions are considered next and achievement measures identified. These measures are calculated for each solution and solutions ranked in order. The result is a detailed specification of essential structural properties of an adequate handling system.

Handling activities identified in Chapter Three comprise two components; (1) the material(s) being transferred, and (2) the transfer path(s). Each of these components can be described in broad terms; the material as either discrete solid, bulk solid, liquid, or gas, while major geometrical properties of the transfer path may be described by its length and cross-sectional dimensions. This description provides an outline of the handling task(s) the designer believes necessary.

More detail is required before any possible solutions can be chosen; this is the role of the second component of the design system. Four classes of properties must be identified:

(1) Properties of the material such as volume, size, shape, weight, temperature, and density are important.

(2) Major geometrical features of the transfer path such as its gross length, shape including gradients, horizontal and vertical displacements, and variation in shape with time.

(3) Rate of material transfer (expressed as number of items transferred per hour, or volume per hour, for example) as a function of time. Differences in short or long term transfer rates identify storage needs.

(4) Constraints upon material flows including:

(a) Control requirements such as monitoring material flow rates monitoring quality of the material, monitoring timing of transfers, placement and positioning of material, and so on.

(b) Process constraints such as material flow rates, safety and prevention of damage to the material.

Sufficient information is now available to decide whether two or more handling activities may be combined into one. This decision depends upon similarity between materials, transfer path shapes, rates of transfer, and timing of transfers.

The design sequence developed this far is illustrated in Figure 9.2.

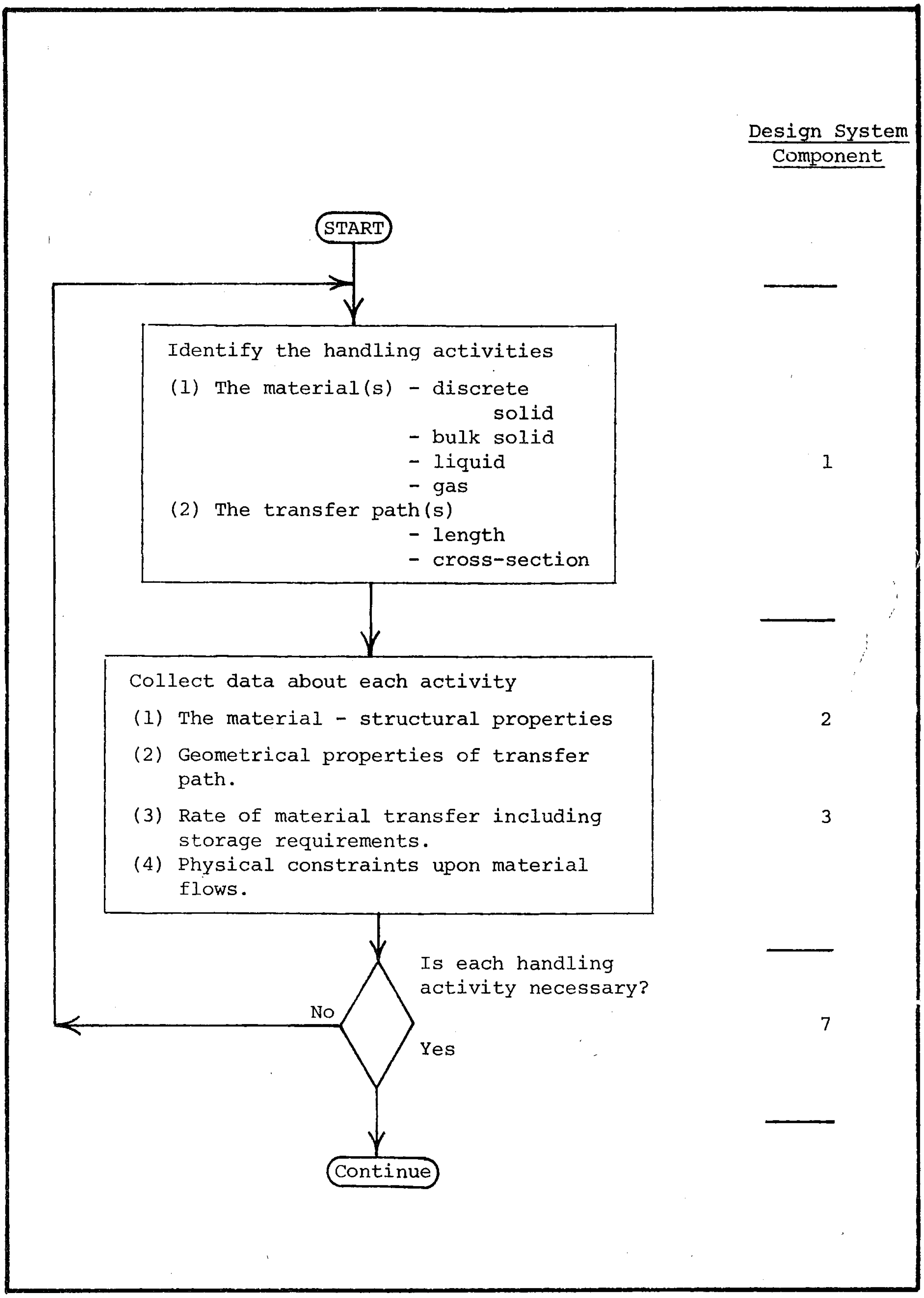


FIGURE 9.2 THE INITIAL PHASE OF THE DESIGN PROCEDURE

Another decision needs to be made at this stage, namely whether the material should be transferred in batches or continuously. This is a major decision in the selection of handling equipment because it deletes consideration of a large proportion of possible handling equipment and changes storage and control requirements for the handling activity. There are general design rules used in practice (23) to make this decision (1) such as:

(1) The rate of material transfer remains steady with time then a continuous mode should be adopted.

(2) Longer transfer paths are less practical for continuous modes.

(3) Permanent transfers are preferably performed in a continuous transfer mode.

(4) Bulk materials should be transferred in a continuous mode; discrete materials should be transferred in a batch mode.

This decision is illustrated in the design procedure in Figure 9.3 [A]. Any decision, though contingent, influences data collected for each transfer. Feedback is provided for this purpose as illustrated in Figure 9.3 [B].

Having decided tentatively on the mode of transfer, additonal data can be collected describing the physical environment which constrains the transfer. These constraints can be grouped as either; (1) physical constraints affecting the material or performance of equipment selected, or (2) organisational constraints which limit the operation of any proposed handling system. Physical constraints include:

(1) Geometry of the surroundings which affects the shape of the transfer path.

(2) Production processes which impose definite limits upon transfer rate of the material, physical condition of the material such as its temperature, orientation during transfer, human operator requirements, and so on.

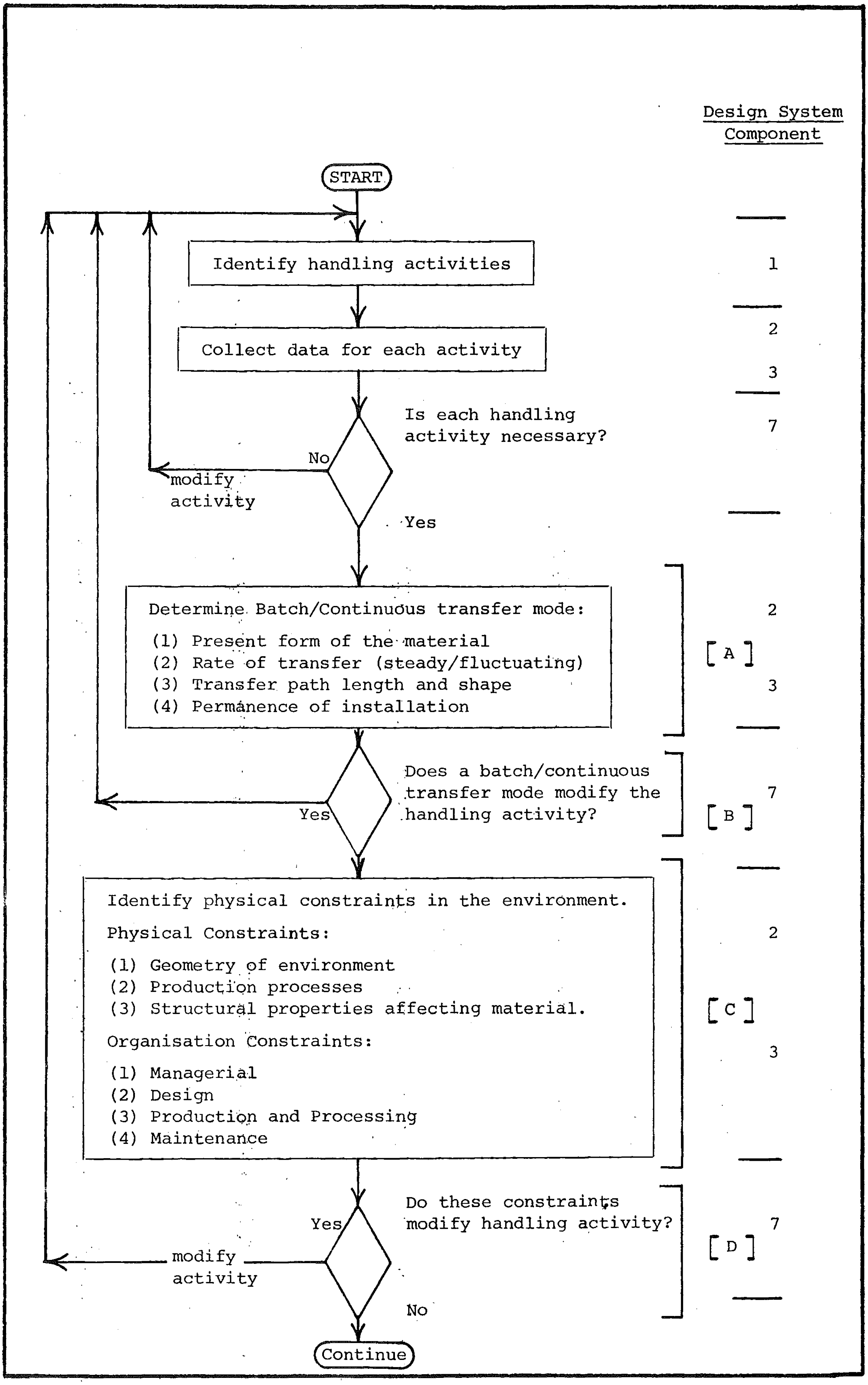


FIGURE 9.3 THE DATA GATHERING PROCEDURE

(3) Specific structural properties of the environment may adversely affect the material or equipment during transfer. For example it may be necessary to protect the material and/or equipment from climatic conditions, dirt, contamination, and so on.

Organisational constraints include:

(1) Managerial constraints such as finance, timing of the design project, limitations on manpower, and management policy on mechanisation constrain the designer's choice.

(2) Design constraints arise from personal limitations of the designer, his experience, his ability to search for alternative solutions, his creative ability, and recognition of novel solutions, are all typical.

(3) Apart from technical constraints imposed by production processes, the designer should be aware of any social or political factors which may influence acceptability of a proposed design. For example production staff may need to be informed or educated to accept, and work with, alternative handling equipment.

(4) Maintenance constraints include limitations on manpower, expertise, and maintenance equipment. These limits should be identified by the designer.

Figure 9.3 [C] illustrates addition of these constraints to the design procedure, whilst 9.3 [D] provides a feedback loop for any changes constraints may produce in the description of the handling activity.

This design procedure has now identified all major classes of properties necessary to describe and constrain a handling activity. The next logical step is to implement the fourth component of the design system, namely, identifying classes of equipment that are likely to provide physically feasible solutions. As discussed in section 9.2, this procedure is largely intuitive, based upon experience, and directed by information gathered for each handling activity by the preceding sequence. No logical processes can be identified to emulate intuition in general for handling system design.

Where no solution can be found then either the designer's knowledge and understanding are insufficient to identify a solution, or the handling activity needsto be modified until a feasible solution can be found. Figure 9.4 [E] illustrates additon of this component to the design procedure.

In practice, availability of any class of equipment such as conveyors, cranes, trucks, and the like, will influence the design procedure. By "availability" is meant that equipment selected can be obtained within a time, and at a cost acceptable to the designer's client. If handling equipment of the appropriate class is available, the designer may proceed to specify equipment in greater detail. Otherwise alternative equipment must be found or the handling activity modified. Figure 9.4 [F] illustrates this feedback loop.

Provided the desired class of equipment is available, additional data describing the handling activity is determined by examining compatibility between equipment selected and the material, the environment within which handling is performed, and other handling equipment. Consider these compatibilities in detail.

(1) Equipment-Material compatibility: Undesirable physical interaction between material and equipment such as chemical, thermal, or abrasive interactions must be identified. Special properties of the material which may reduce equipment operational efficiency such as air-entrainment in bulk powders,or the ability of certain grades of bulk solids to "hang-up" in hoppers, have to be identified.

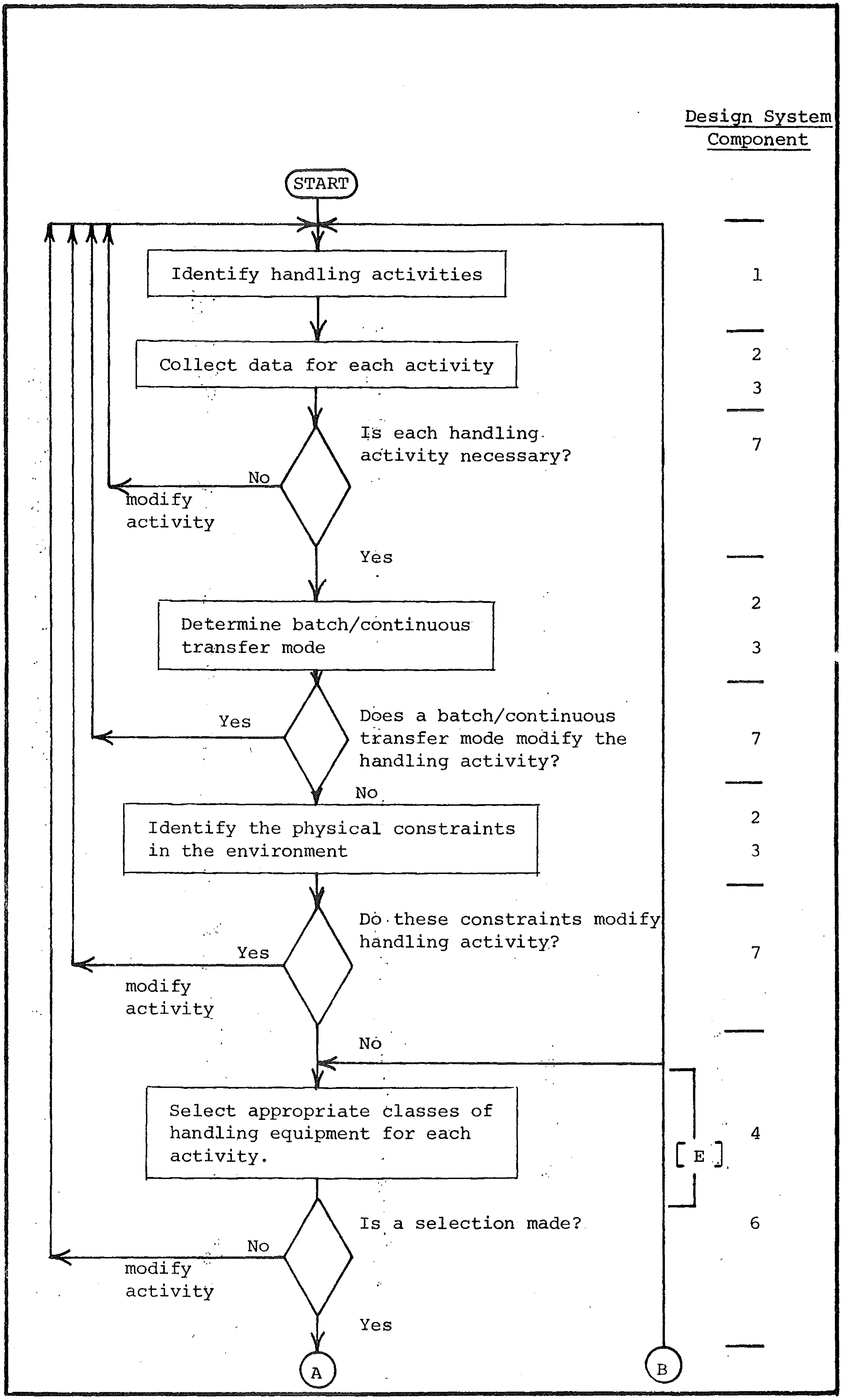

Design System Component
START
Identify handling activities
1
Collect data for each activity
2
3
Is each handling activity necessary?
7
No
modify activity
Yes
Determine batch/continuous transfer mode
2
3
Does a batch/continuous transfer mode modify the handling activity?
Yes
7
No
Identify the physical constraints in the environment
2
3
Do these constraints modify handling activity?
Yes
modify activity
7
No
Select appropriate classes of handling equipment for each activity.
[E]
4
Is a selection made?
6
No
modify activity
Yes
A
B

FIGURE 9.4

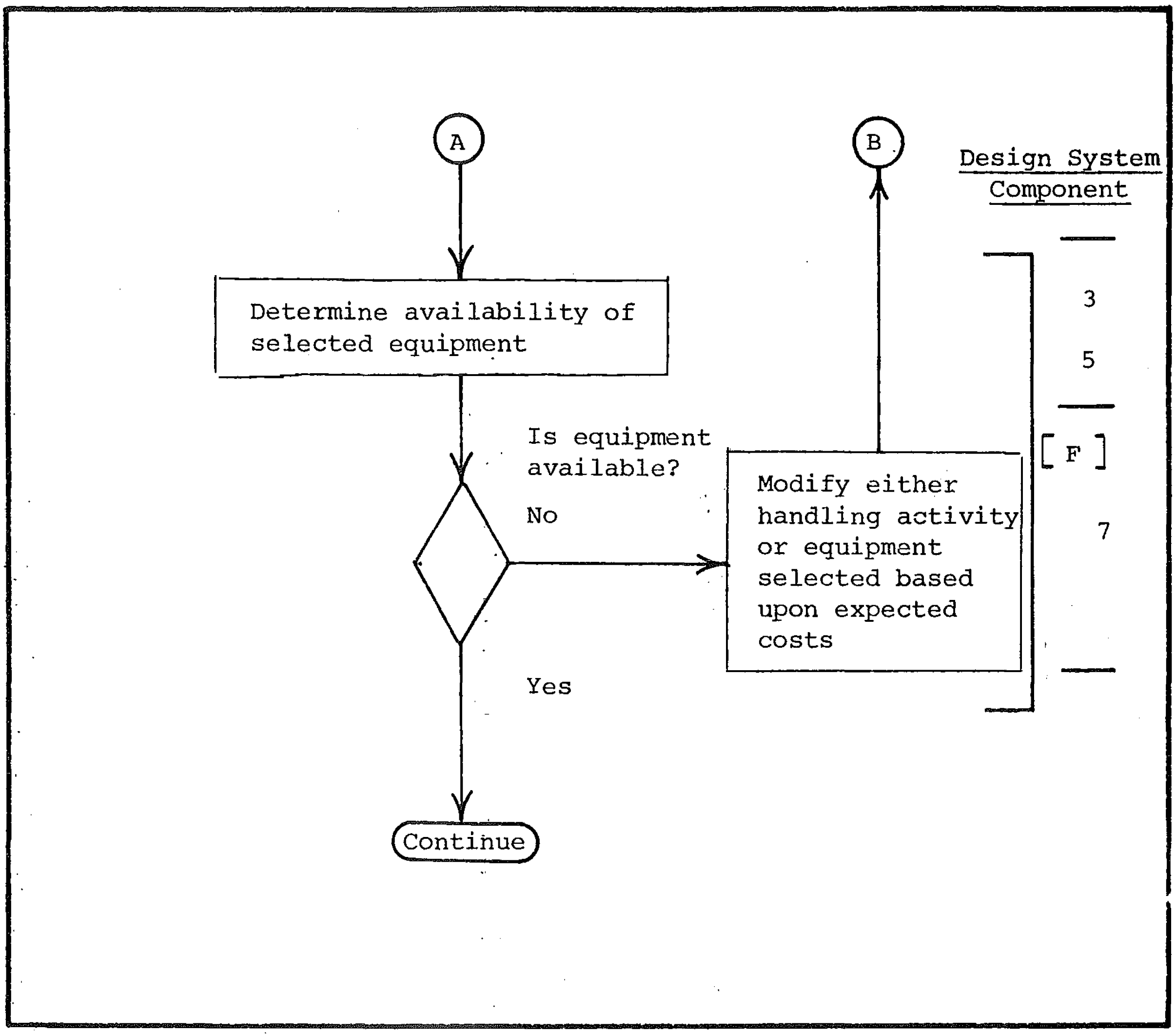


FIGURE 9.4 THE DESIGN PROCEDURE ILLUSTRATING SELECTION OF EQUIPMENT

(2) Equipment-Environment interaction: Size and shape of handling equipment must be compatible with the environment within which it is to operate. Aisle width, door width and height, road width and turning space, all must be examined for compatibility. Changes in structural properties, in addition to geometrical properties, must be identified. These include effects of weather on equipment, or, effects of equipment on environment such as pollution by exhaust fumes or noise. Production processes may influence temperature and humidity of the working environment or they may require performance of control actions during handling such as monitoring material flow rates, weighing unit loads, counting loads, or, quality controls such as visual inspection of material, timing of material transfers, and so on. Handling equipment selected must be compatible with each of these possibilities.

(3) Equipment-Equipment interaction: Items of handling equipment must be compatible one to the other both geometrically and functionally. That is, material must be able to be transferred from one item of handling equipment to the next, which may involve selection of additional handling equipment.

Incompatibilities in any of the above three classes can be eliminated by changing handling equipment, the handling activity, the environment, or a combination of these. The particular course of action chosen depends upon expected costs; the cheapest alternatives being the best. For illustrative purposes these compatibility relations are taken as a group and added to the design procedure in Figure 9.5 [G].

Thus far the design procedure has attempted to obtain an acceptable solution to each handling activity without changing initial structural properties of the material. If no acceptable solution can be found, packaging or unitising the material may provide an acceptable solution.

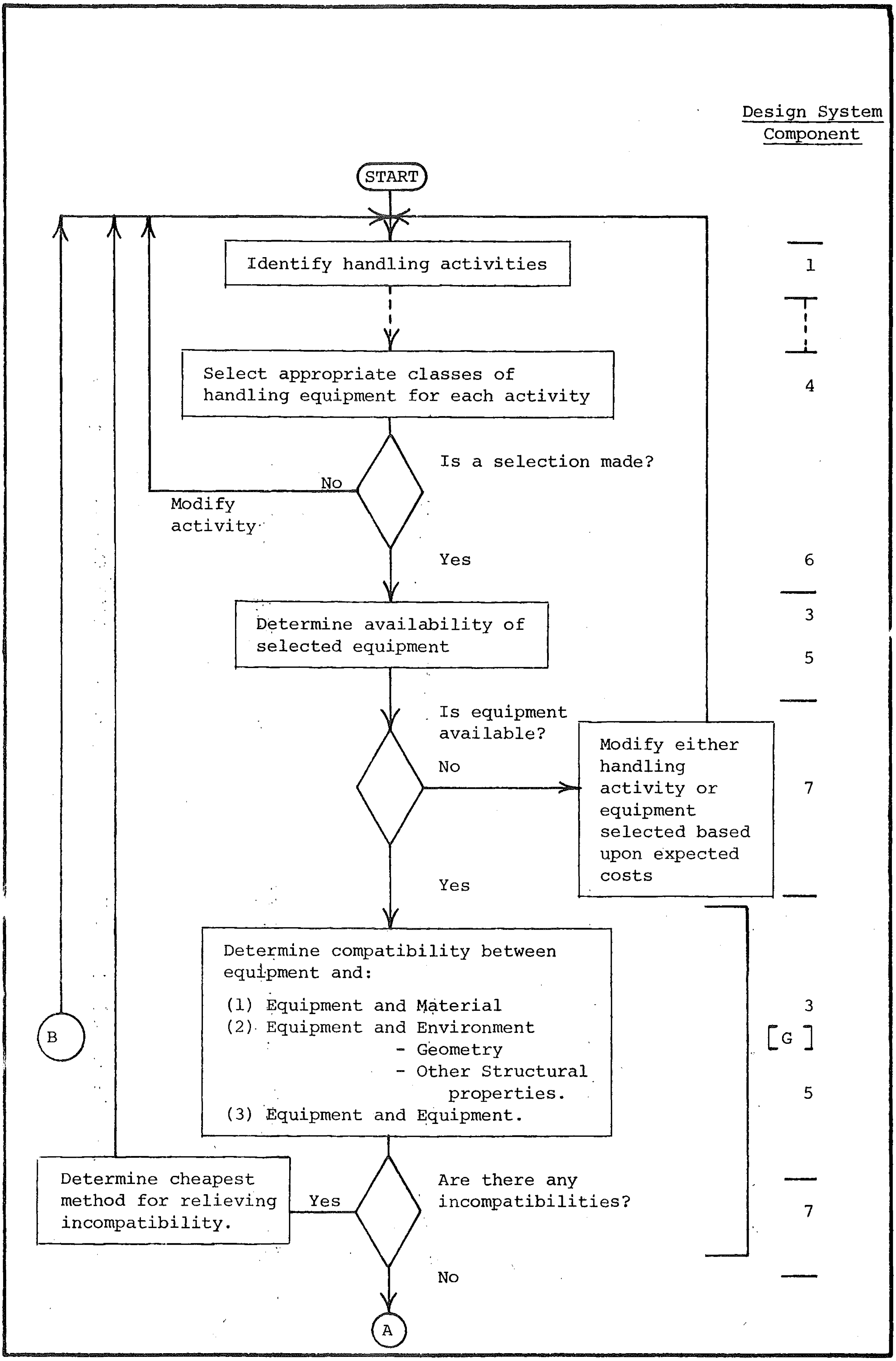

Design System Component
START
Identify handling activities
1
Select appropriate classes of handling equipment for each activity
4
Is a selection made?
No
Modify activity
Yes
6
Determine availability of selected equipment
3
5
Is equipment available?
No
Modify either handling activity or equipment selected based upon expected costs
7
Yes
Determine compatibility between equipment and:
(1) Equipment and Material
(2) Equipment and Environment
- Geometry
- Other Structural properties.
(3) Equipment and Equipment.
3
[G]
5
B
Determine cheapest method for relieving incompatibility.
Yes
Are there any incompatibilities?
7
No
A

FIGURE 9.5

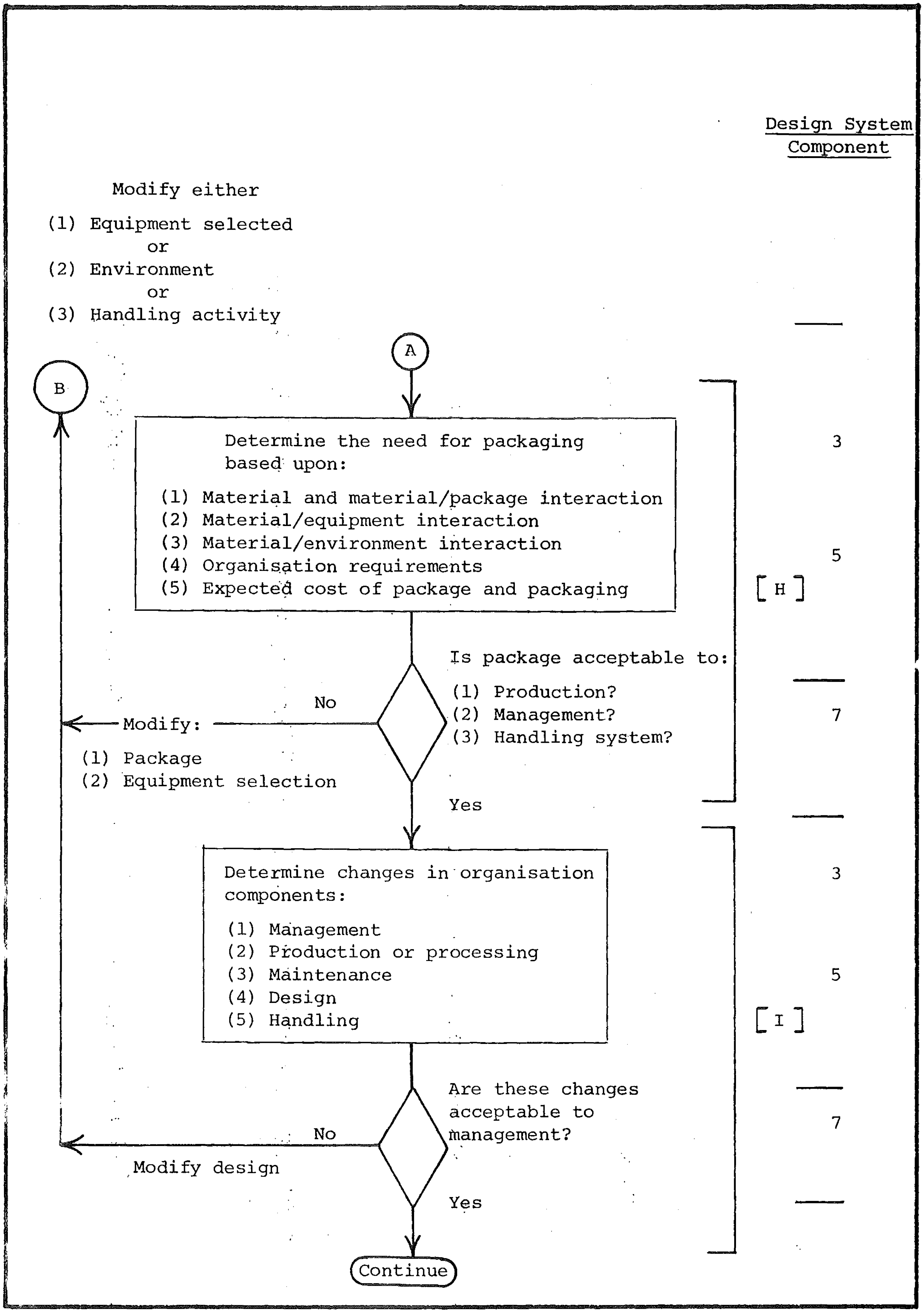


FIGURE 9.5 THE COMPLETED SELECTION PROCEDURE

Packaging and unitising decisions are closely related to batch/continuous decisions and one cannot be considered independently of the other. Five classes of properties have been identified (24, 25) as being relevant to this decision.

(1) Structural properties of the material such as its size and weight, whether it is fragile, its value, and compatibility of the material with its package all constrain the type of package.

(2) Any undesirable interaction between proposed handling equipment and material indicate a need for a package.

(3) Protecting material from the environment such as climatic conditions, dirt, and mechanical damage indicates the need for a package.

(4) Organisational requirements imposed by management regarding supplier and customer demands indicate a need for, and type of package required.

(5) Expected cost of the package including costs of packaging constrains the type of package.

If a decision is made in favour of packaging, a review of equipment selected is necessary. The packaging decision is added to the design procedure as illustrated in Figure 9.5 [H] together with feedback loop to review equipment selected.

During the design procedure the designer must identify changes in the components of the organisation resulting from his equipment selections. Chapter Eight identified these components as: (1) management, (2) production or processing, (3) maintenance, (4) design, and (5) handling.

One of management's functions, from the point of view of a handling system, is to control resources. Therefore the designer must identify additional resources required to design, install, and operate his proposed system. These include technical manpower to design, operate, and regulate the system, supplies of energy such as fuel, and finance to enable the purchase of these resources. Time required to install the system must also be determined.

Production or processing systems may be affected by changes in plant layout, process sequencing, and production scheduling. For example in case study four (Chapter Six) provision was made to reposition production machines in order to optimise robot cycle time.

Changes in handling equipment may require a change in components of the maintenance system. Typically this would include changes in expertise, equipment, and resources allocated to maintain the handling equipment. For example, introduction of industrial robots into a manufacturing company requires the company to possess or have access to a high level of technical expertise in electronics.

Existing staff in the organisation may not possess sufficient knowledge and understanding to produce a satisfactory design. This is overcome by education or by engaging specialist consultants.

Specifying new handling equipment changes the handling system. In particular methods for planning and scheduling handling equipment together with resources required such as manpower and finance must be identified and determined.

Each such change will incur some cost which must be acceptable to management. Provision is made to test for acceptability of these changes as illustrated in Figure 9.5 [I].

All technical and organisational factors have been identified for selecting items of handling equipment, and feasible combinations of equipment selected. Logically then, the next stage of the design procedure is to identify achievement measures for the feasible handling systems. This is component eight of the design system in section 9.2. As discussed in section 9.2 these measures must distinguish between technically and organisationally feasible alternatives to determine the best alternative, and for this alternative indicate how well it performs the handling activities for which it was designed. Achievement measures are usually quantified in monetary terms which may be divided into nine classes.

(1) Capital cost of equipment.

(2) Installation and commissioning costs.

(3) Expected running costs including energy costs.

(4) Labour costs, both hiring and training.

(5) Expected maintenance costs, including purchasing maintenance equipment.

(6) Expected design costs.

(7) Expected costs arising from changes in production activities.

(8) Expected management costs including staffing and changes to management procedures.

(9) Legal costs incurred in obtaining approval of a proposed system. In particular with regard to union labour award agreements, and safety, and patent requirements.

Optimising the cost of a handling system was discussed in the previous chapter. The alternative which minimises these costs for the organisation is the optimum handling system. Figure 9.6 illustrates the addition of component eight to the design procedure.

In the event of no alternative being found acceptable to organisation management or the designer's client, provision must be made to re-examine handling activities from the beginning. Component nine is illustrated in Figure 9.6.

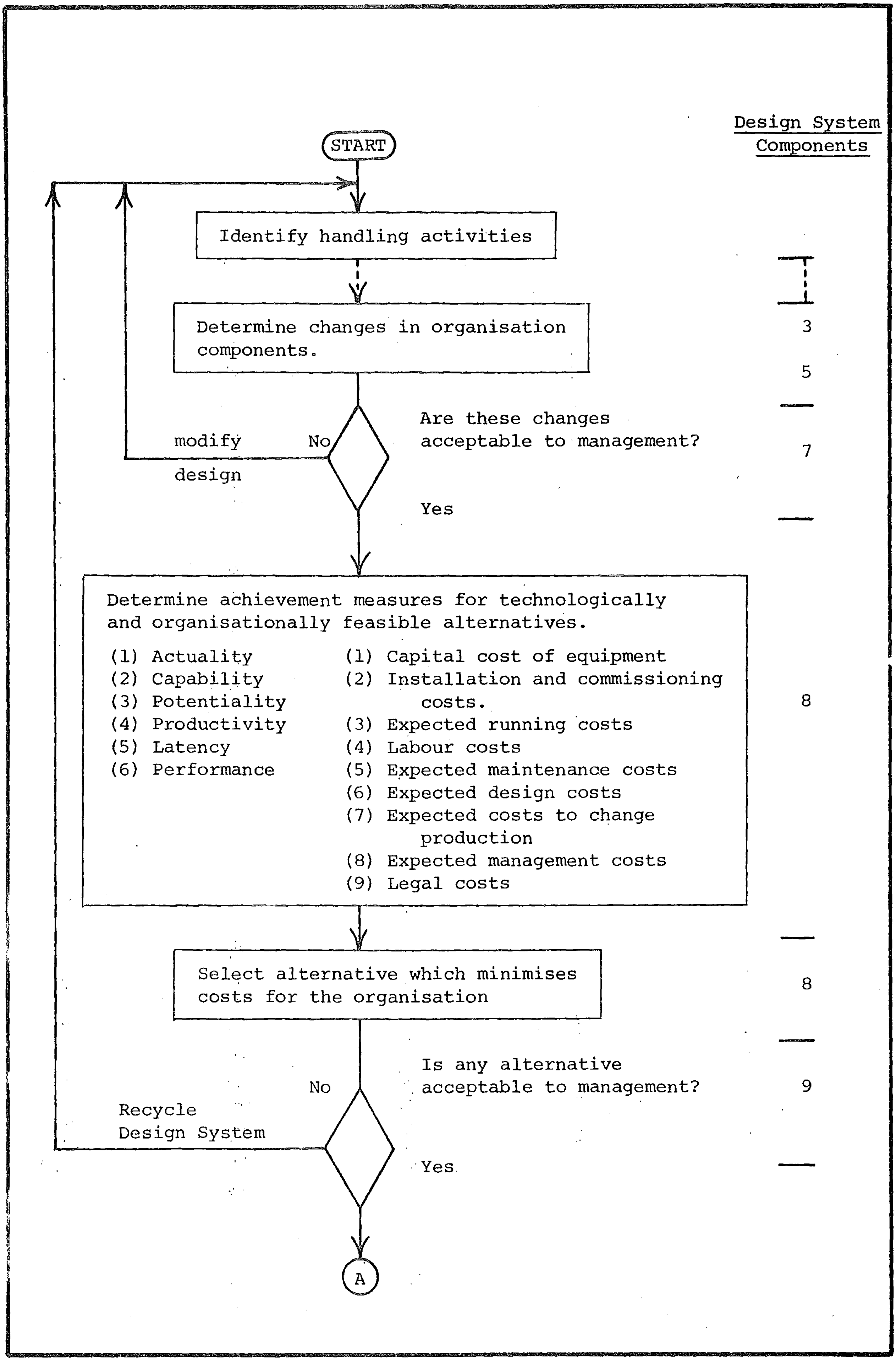

Design System Components
START
Identify handling activities
Determine changes in organisation components.
3
5
modify design
No
Are these changes acceptable to management?
7
Yes
Determine achievement measures for technologically and organisationally feasible alternatives.
(1) Actuality
(2) Capability
(3) Potentiality
(4) Productivity
(5) Latency
(6) Performance
(1) Capital cost of equipment
(2) Installation and commissioning costs.
(3) Expected running costs
(4) Labour costs
(5) Expected maintenance costs
(6) Expected design costs
(7) Expected costs to change production
(8) Expected management costs
(9) Legal costs
8
Select alternative which minimises costs for the organisation
8
Recycle Design System
No
Is any alternative acceptable to management?
9
Yes
A

FIGURE 9.6

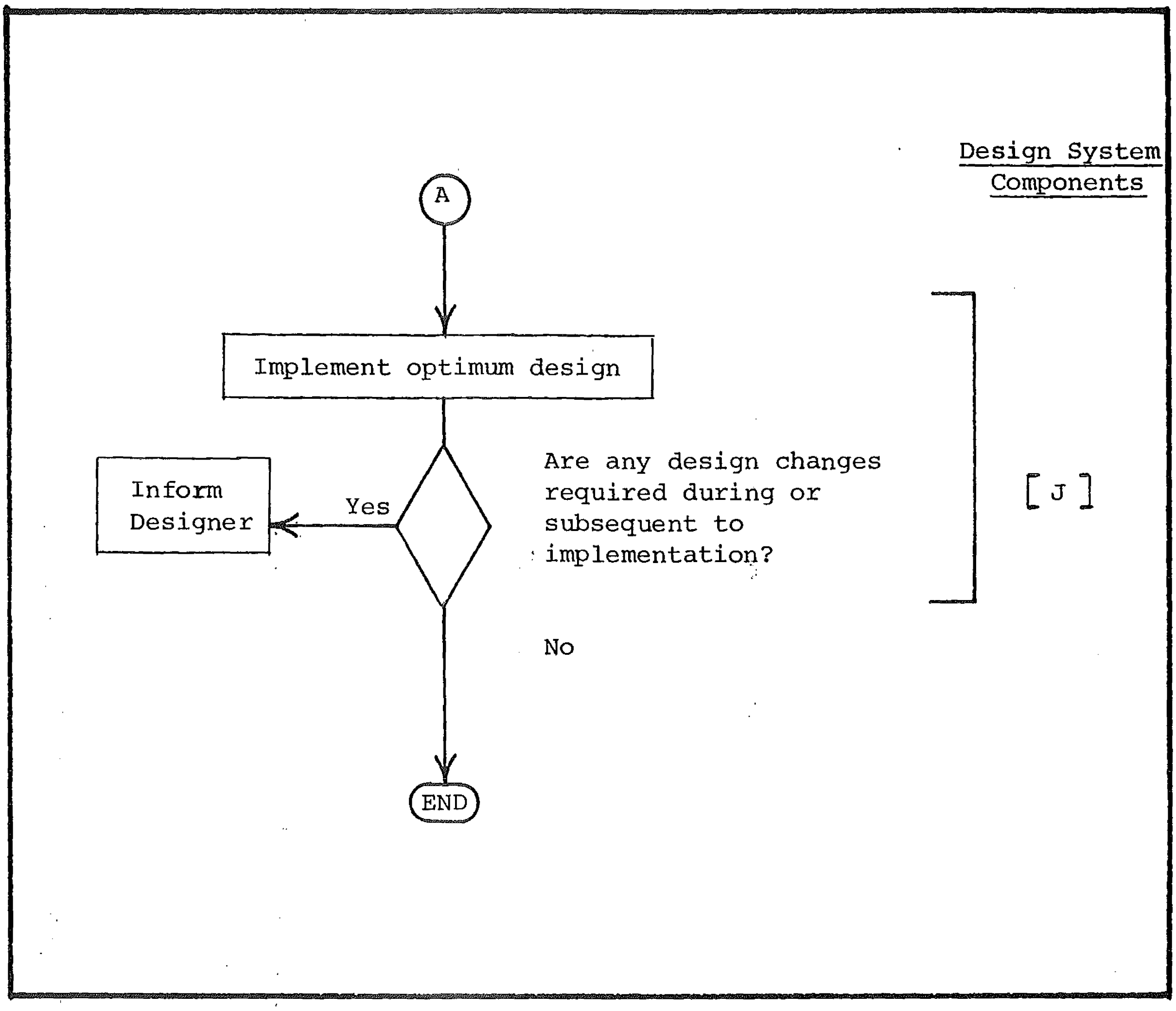


FIGURE 9.6 ACHIEVEMENT MEASURES IN THE DESIGN PROCEDURE

With identification and approval of suitable achievement measures for the proposed handling system, the designer's task is virtually complete. Implementing this design may expose weaknesses or errors, therefore a feed-back line is provided to the designer which is illustrated in Figure 9.6 [J].

The completed design procedure is illustrated in Figure 9.7.

9.4 Automating the Design Procedure

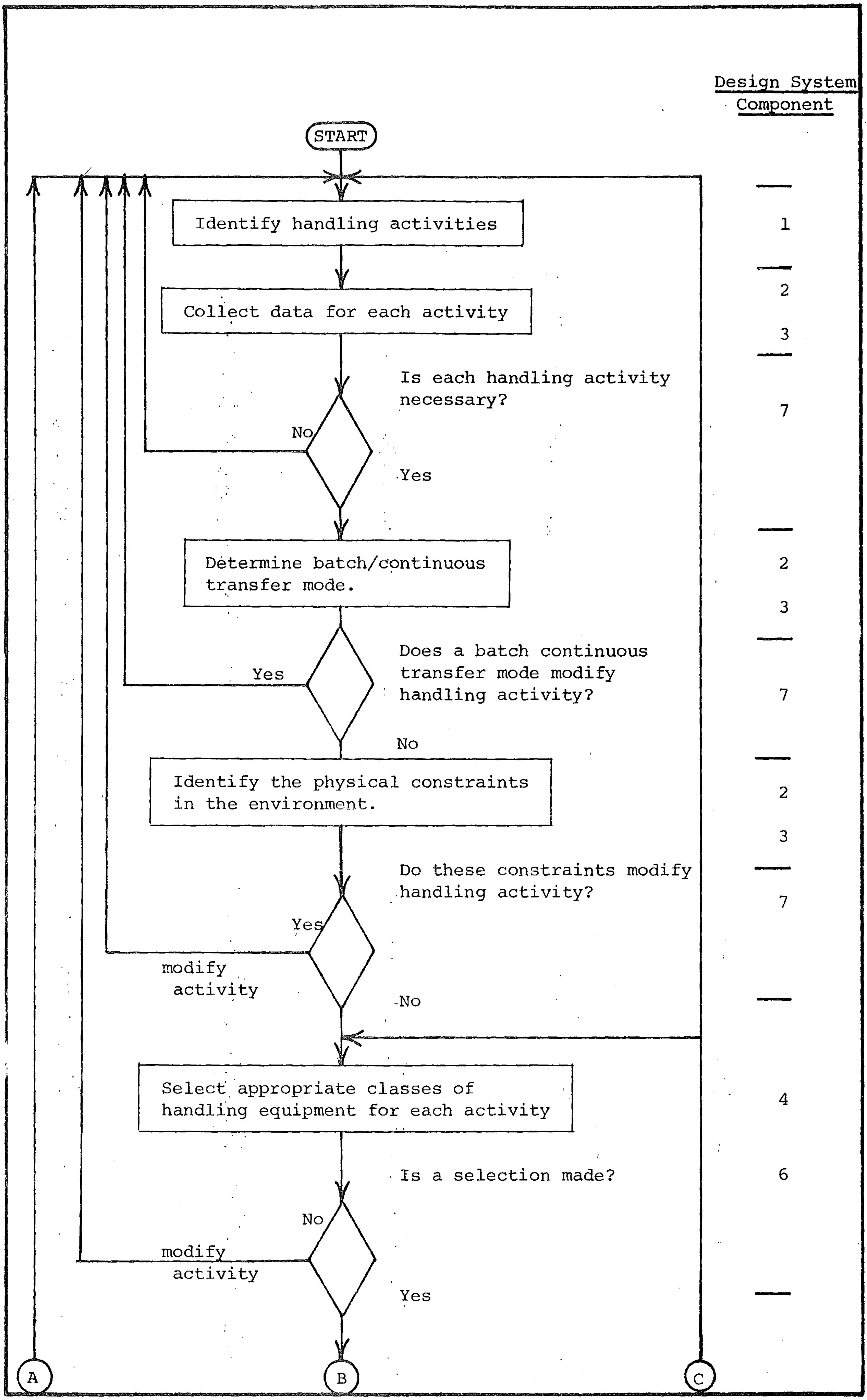
Part of the objective of this research involves determining which components of the design system can be solved logically and hence automated, and which require intuitive ability of human designers.

Consider each component of the design system presented in section 9.2 in terms of the structure identified for automated design routines identified in Part One.

Component One: A person is necessary to recognise that a handling problem is a member of a particular class of problems for which an automated design routine is available. This involves abilities in complex pattern recognition.

Components Two and Three: Collecting data and determining its relevance may be formalised whenever the essential features of a class of handling activities can be made explicit. In general this is not practicable, but for particular cases as exemplified by case study four (Chapter Six) closed sets of properties can be found. Identifying these sets of properties was a major task in each case study examined. A human designer is required to encode each problem according to a defined format.

Components Four, Five, and Six: To automate these components required that classes of handling equipment can be found which represent an exclusive and exhaustive set of possible solutions to a class of problems. Also an explicit set of relationships must be identified which relate problem to



Design System Component
START
Identify handling activities
1
Collect data for each activity
2
3
Is each handling activity necessary?
7
No
Yes
Determine batch/continuous transfer mode.
2
3
Does a batch continuous transfer mode modify handling activity?
7
Yes
No
Identify the physical constraints in the environment.
2
3
Do these constraints modify handling activity?
7
Yes
modify activity
No
Select appropriate classes of handling equipment for each activity
4
Is a selection made?
6
No
modify activity
Yes
A
B
C

FIGURE 9.7

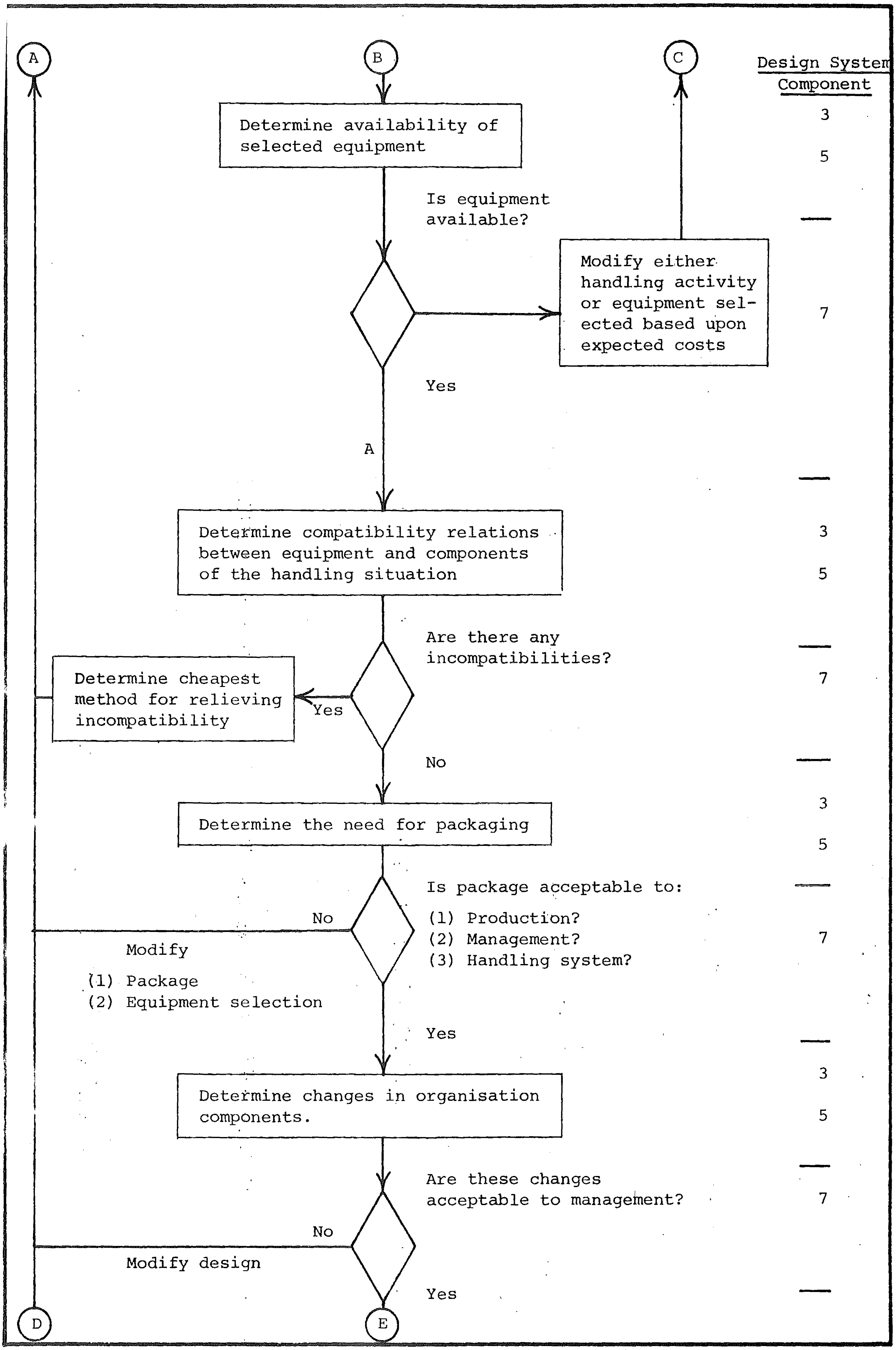

A
B
C
Design System
Component
Determine availability of selected equipment
3
5
Is equipment available?
Modify either handling activity or equipment selected based upon expected costs
7
Yes
A
Determine compatibility relations between equipment and components of the handling situation
3
5
Are there any incompatibilities?
Determine cheapest method for relieving incompatibility
Yes
7
No
Determine the need for packaging
3
5
Is package acceptable to:
(1) Production?
(2) Management?
(3) Handling system?
No
Modify
(1) Package
(2) Equipment selection
7
Yes
Determine changes in organisation components.
3
5
Are these changes acceptable to management?
7
No
Modify design
Yes
D
E

FIGURE 9.7

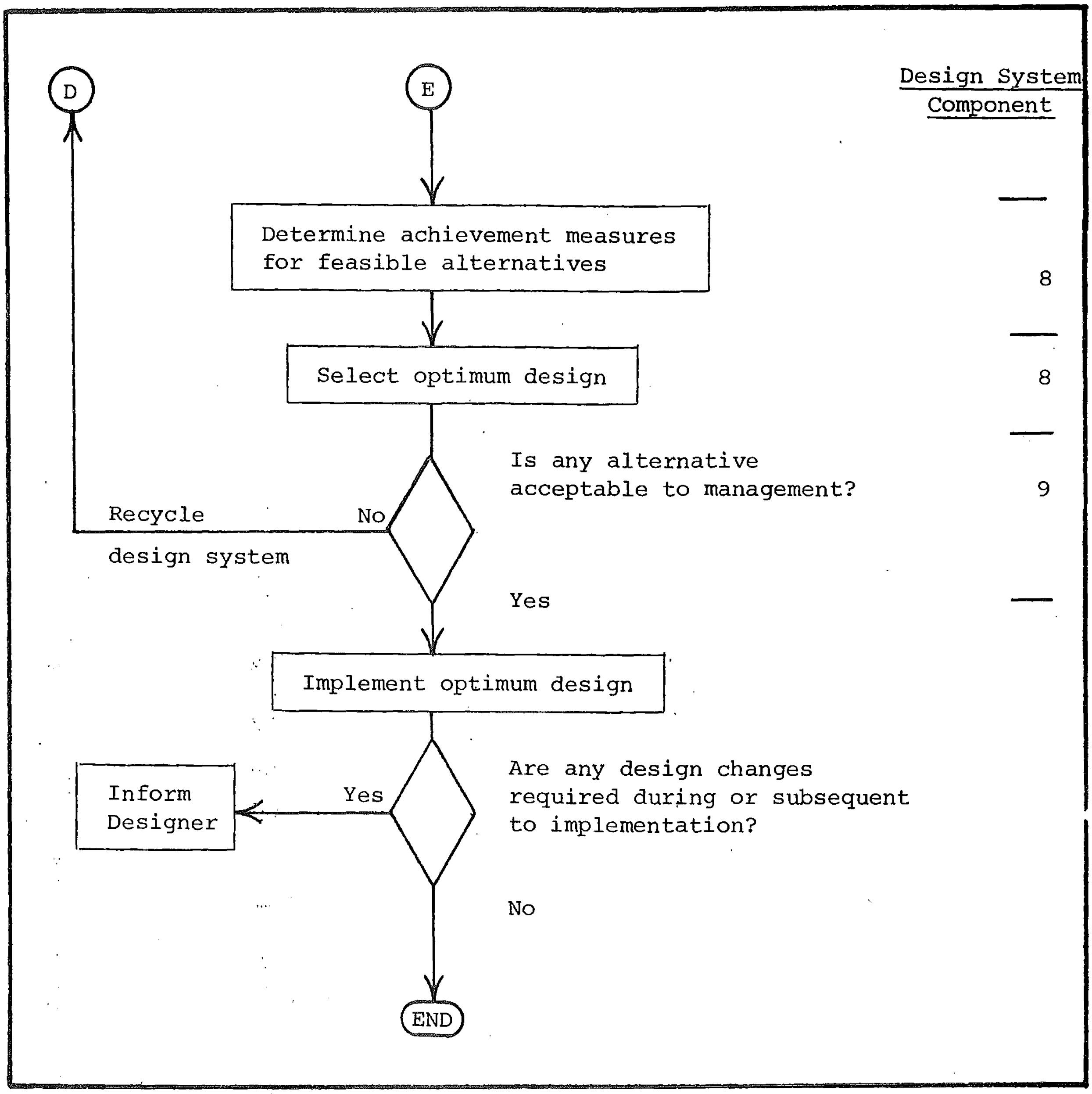


FIGURE 9.7 THE COMPLETE HANDLING SYSTEM DESIGN PROCEDURE

solution. In general no such set of relationships could be found for any particular item of handling equipment. Furthermore, material handling science does not possess a rigorous theory to transform problem description variables into solution description variables as does say, vibration theory, as exemplified in case study one. The only form of such a theory in handling system design are subjectively stated principles. In particular cases objective relationships may be found. This is a difficult task.

If such relationships can be determined it is not always necessary to make objective the reasons why one alternative solution is chosen from among several possible alternatives. Provided all alternatives are identified, a human designer may make a choice using his intuition which the computer may subsequently evaluate according to defined procedures. This is the approach used in interactive computer design aids.

Components Seven and Eight: Wherever achievement measures can be made explicit then the computer can evaluate the achievement of any proposed alternative system. It may be desirable to allow the human designer to choose which criteria he wants to evaluate any solution, but provided the alternatives are explicitly defined then the computer can calculate each achievement measure. Developing suitable achievement measures is always a difficult task.

Component Nine: Whether any solution is satisfactory must ultimately be determined by the human designer or his client.

For any class of handling system design problems it is conceivable that the assistance a computer can provide ranges from none in ill-defined problem situations which need only be solved once, to completely automated procedures capable of providing detailed specifications of an optimum handling system for often repeated design problems. Between these extremes a range of interactive programs may be envisaged. The extent of interaction depends upon the economics of committing research effort to make explicit the design situation.

CHAPTER TEN

THE DESIGN OF A BAGGAGE HANDLING SYSTEM - A CASE STUDY

10.1 Introduction

The objective of this chapter is threefold:

(1) To illustrate application of the logical handling system design procedure.

(2) To demonstrate that the logical design procedure is capable of making explicit a comprehensive set of design data and assumptions which can be used to select handling equipment. The logical sequence in which this data is gathered and decisions made must be illustrated.

(3) To show that a logical design procedure has potential to produce more capable handling systems with fewer errors than human designers.

In fulfilling the first objective the design procedure must be applied to an actual handling system design situation. The second and third objectives are more difficult. They require that the logical procedure be compared with present design methods, namely inferential processes used by human designers, to determine whether a logical approach has potential to produce more capable designs. A case study was found in which detailed design reports, prepared by experienced designers, were made available for examination. This involved designing an improved baggage handling system for the domestic terminal at Wellington Airport.

This chapter is divided into three parts. The first part presents the case study in the form prepared by the designers including their proposed solutions. The second part examines the handling situation using the logical design procedure to illustrate its application in designing handling systems. The third part compares each approach to illustrate how a logical approach can produce more capable handling systems.

10.2 The Design Produced By Experienced Designers

Experienced human designers were presented with the task of recommending suitable equipment layouts for the baggage handling system in the domestic terminal at Wellington Airport.

To place this objective in perspective, a brief description of the overall baggage handling activity is given with aid of Figure 10.1. Passenger baggage enters the handling system at the baggage check-in counter where each passenger is allocated his seat number. Each bag is identified with its owner, the final destination, any transhipment points, and each aircraft upon which it is travelling. The bags are then dispatched by conveyor, or by hand, to the baggage makeup area where human loaders place them onto baggage carts designated to each aircraft. Baggage may travel to its owner's destination ahead of, or on the same flight as its owner. Up to ten separate flights may be serviced within any one hour period, and any bags arriving earlier than one hour before departure of a flight are stored. As each baggage cart is filled, it is hauled manually by the loader to a weighbridge where its net weight is recorded before being towed to the aircraft. Baggage also enters the make-up area from transhipment loads. That is, passengers who change aircraft during their journey can have their bags transferred to the next aircraft without claiming and rechecking it. Transhipment baggage enters the make-up area where it is sorted in the same manner as all direct flight baggage.

Upon arrival of an aircraft all baggage is unloaded onto baggage carts which are towed to the self-claim area where passengers identify and

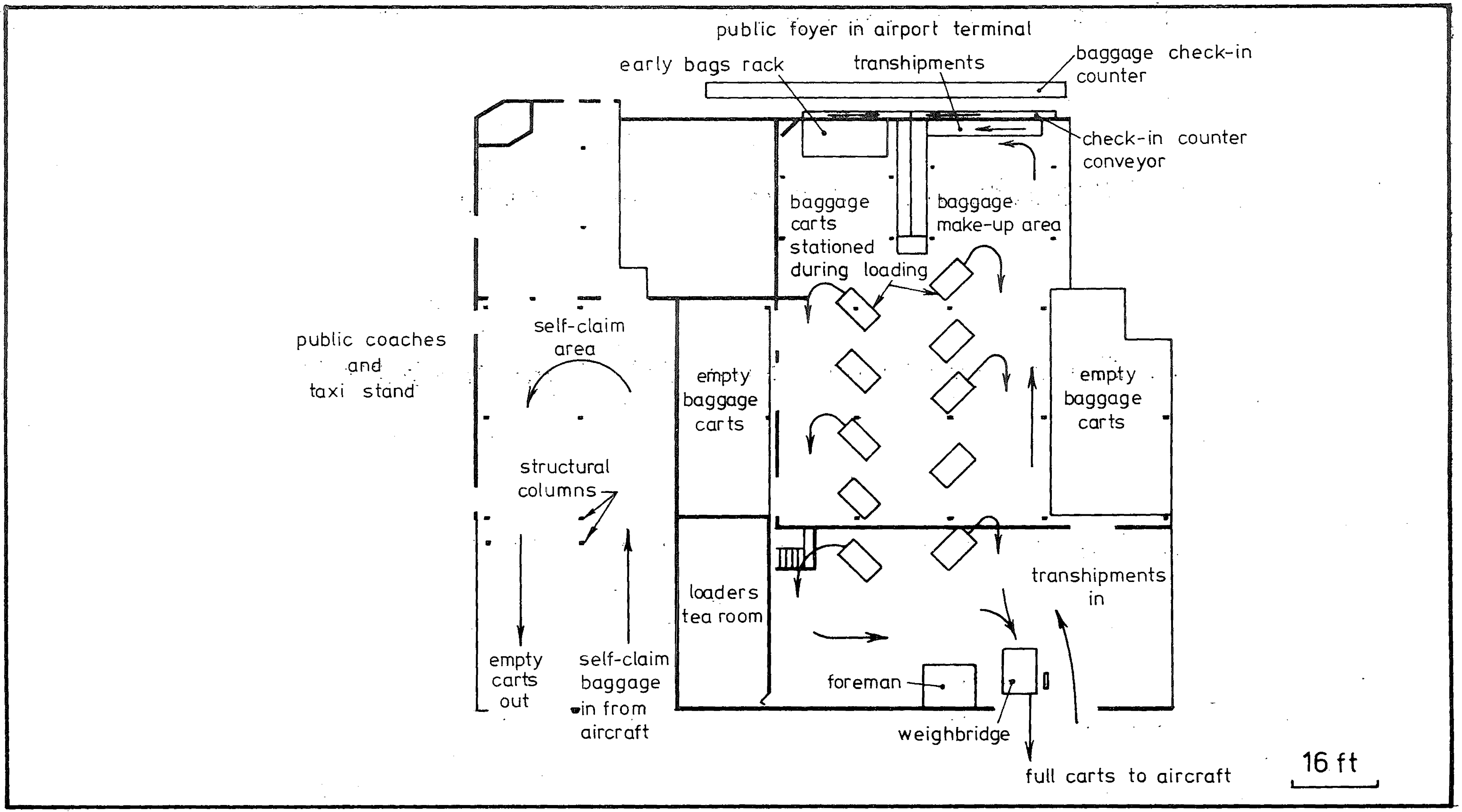


FIG 10·1 PRESENT HANDLING SYSTEM

remove their bags directly from the carts or, in the case of transhipment baggage, is towed to the baggage make-up area.

This system was judged by management, to be unsatisfactory to both public and staff because expected traffic increases would cause substantial staff and hence cost increases. Therefore an investigation of handling methods was implemented to find a more economical solution.

After studying the existing system the designers were led to believe that two activities should be isolated for more detailed examination. These were baggage sorting and make-up and self-claim. Self-claim was judged to be unsatisfactory because safety and convenience with which bags were presented to passengers was declining as traffic flow increased. Customer complaints were also increasing. The cost of performing baggage make-up activities was expected to rise substantially because substantial increases in labour would be necessary given forecast increases in baggage flowrates.

The self-claim activity was analysed taking into account a management decision to make available additional building space suitable for conversion to a self-claim area. Based upon existing projections the self-claim activity had to handle baggage from up to three flights within a fifteen minute period. The maximum service time for one flight was assumed to be fifteen minutes, and trains of baggage carts must not queue for service. Given these conditions two alternatives were proposed:

(1) A partly mechanised system where bags are removed manually from baggage carts by airline staff and placed onto a storage conveyor which presents self-claim bags to passengers.

(2) A manual system similar to the existing system, except utilising additional building space to provide a better customer service.

An economic comparison between these alternatives showed the second as being most acceptable. A feasible layout is illustraged in Figure 10.2.

Analysis of existing baggage sorting and make-up activities resulted in isolation of nine significant points:

(1) Loaders may have to carry bags weighing up to 70lbs a distance of 30 feet or more.

(2) Bags must be removed from the input conveyor immediately upon entering baggage make-up to prevent congestion and subsequent damage. This means staff must be provided for short period peak flows.

(3) Transhipment baggage arriving into the centre of the make-up work area disrupts smooth workflow.

(4) Early bags are held for several hours prior to loading.

(5) Weighing filled baggage carts involves both foreman and loader.

(6) Filled baggage carts are drawn by hand a considerable distance.

(7) Any unusually shaped items which will not travel on the existing conveyor have to be carried by hand into the make-up area.

(8) Manpower required is 56 loader-shifts plus 20 foreman-shifts per week.

(a) The design criterion specified by management was to minimise total cost for the baggage handling system.

Baggage flow rates were believed to be the most important variable constraining choice of equipment. These were known to vary statistically with time, but the only service acceptable to passengers required that their bags should be available for collection on arrival at their destination. The handling system must therefore be designed for peak passenger flow rates. Currently this peak was known and measured at nine bags per minute. A safety margin of one bag per minute was provided intuitively to allow for errors giving a maximum design flow rate of ten bags per minute for 1976.

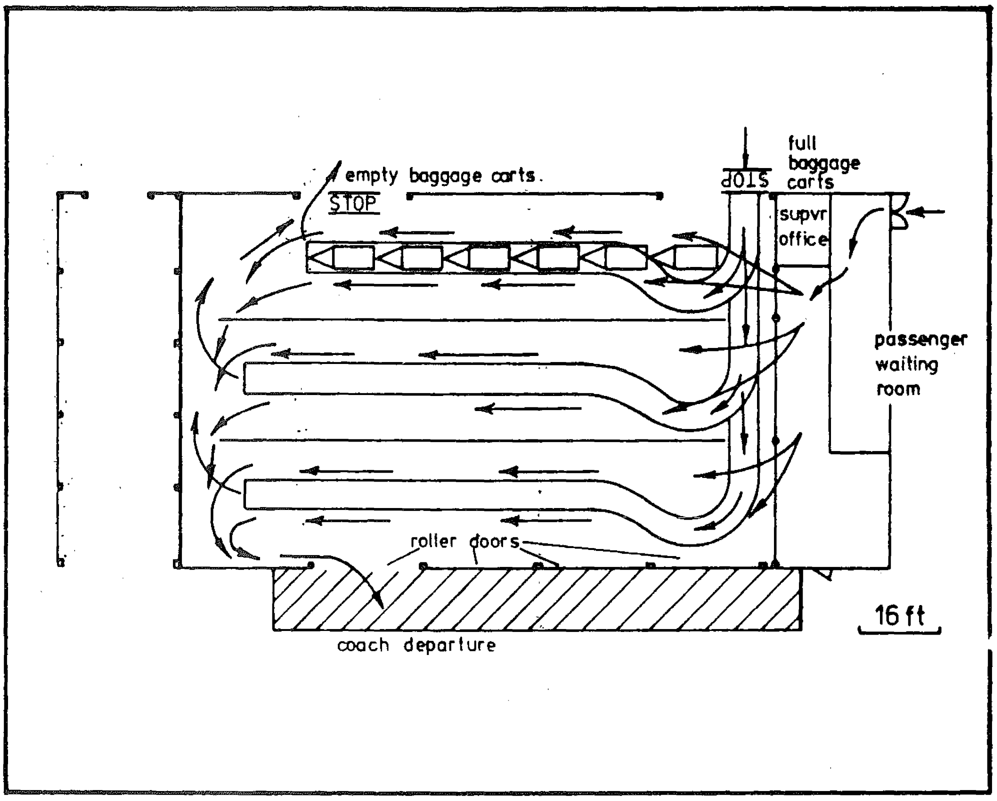


FIG. 10·2 PROPOSED SELF CLAIM LAYOUT.

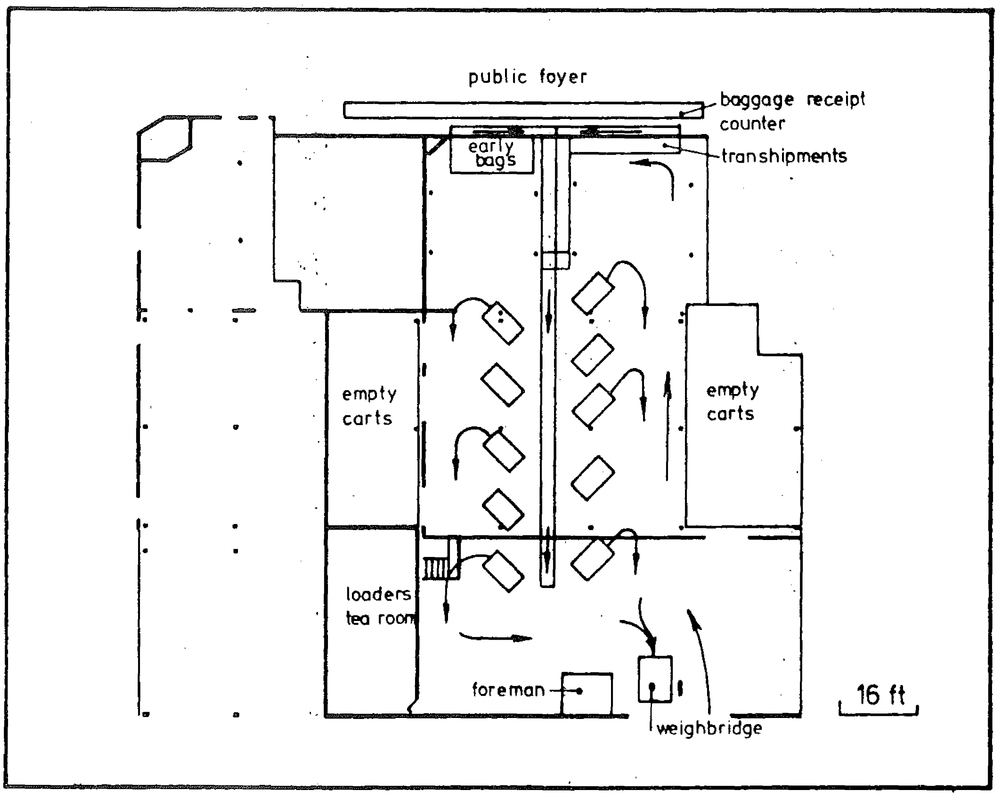


FIG. 10·3 BAGGAGE MAKE-UP USING EXTENDED CONVEYOR SYSTEM

Given a projected growth rate of five per cent per annum and a design life of six years, the handling system must be capable of a maximum flow rate of fourteen bags per minute.

Based upon this information and an implicit understanding of handling activities, three handling methods were proposed to transfer bags from check-in counter to baggage make-up.

(1) An extension of the existing conveyor system. This proposal illustrated in Figure 10.3 relies upon a large manual contribution to transfer peak flow rates. Estimated manhours required to handle peak flows is sixty loader-shifts per week and fourteen foreman shifts per week.

(2) A storage loop system. Bags are delivered from the check-in counter to a circulating storage conveyor. Baggage carts allocated to each flight are placed around its periphery where they are loaded manually. Storage ability of the loop reduces peak flow rates therefore loading staff required is estimated at forty-one loader shifts per week and fourteen foreman shifts per week. This proposal is illustrated in Figure 10.4.

(3) A baggage sorting machine. Bags are conveyed from the check-in counter to a sorter who identifies the destination of each bag and programs the sorting machine. They are then conveyed into the baggage cart area where pre-programmed arms push each bag off the conveyor at the appropriate baggage cart. Each bag slides down a glacis to a storage area from which it is manually loaded onto baggage carts. Estimated staff required is thirty five loader shifts per week and fourteen foreman shifts per week. This proposal is illustrated in Figure 10.5.

The designers observed two further aspects of the existing baggage handling system in which they felt savings could be made. The first concerned a modification to the weighbridge to produce printed values of the net weight of baggage on each cart. This would save one man-shift per

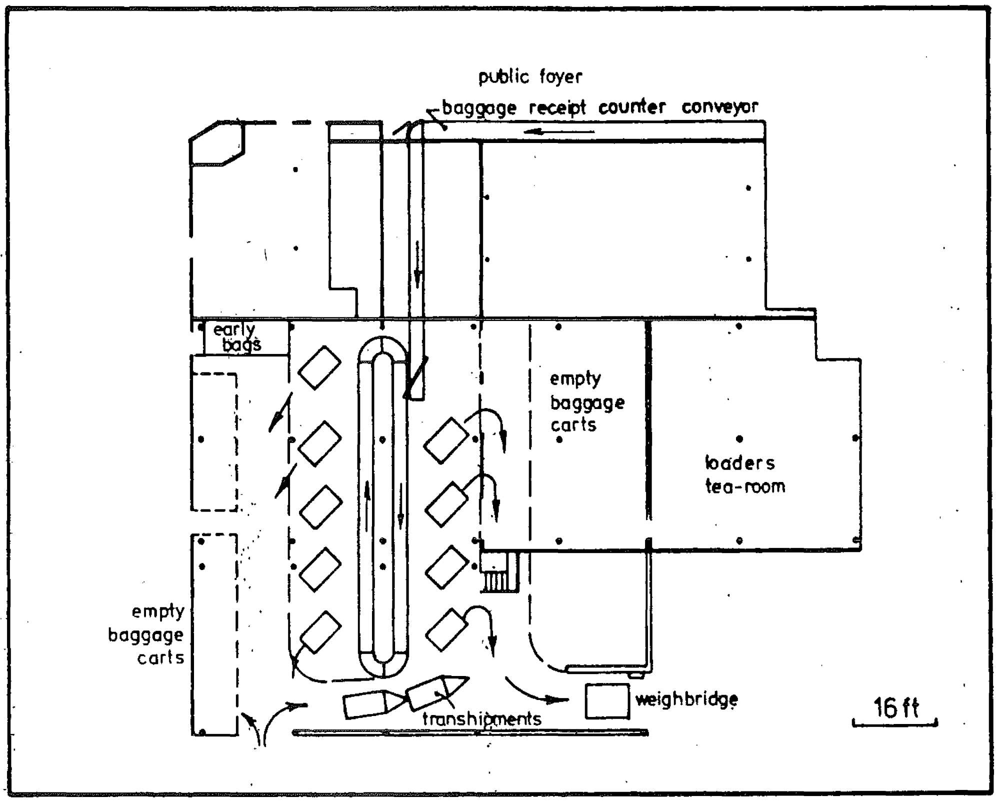


FIG. 10·4 BAGGAGE MAKE-UP USING A STORAGE LOOP SYSTEM.

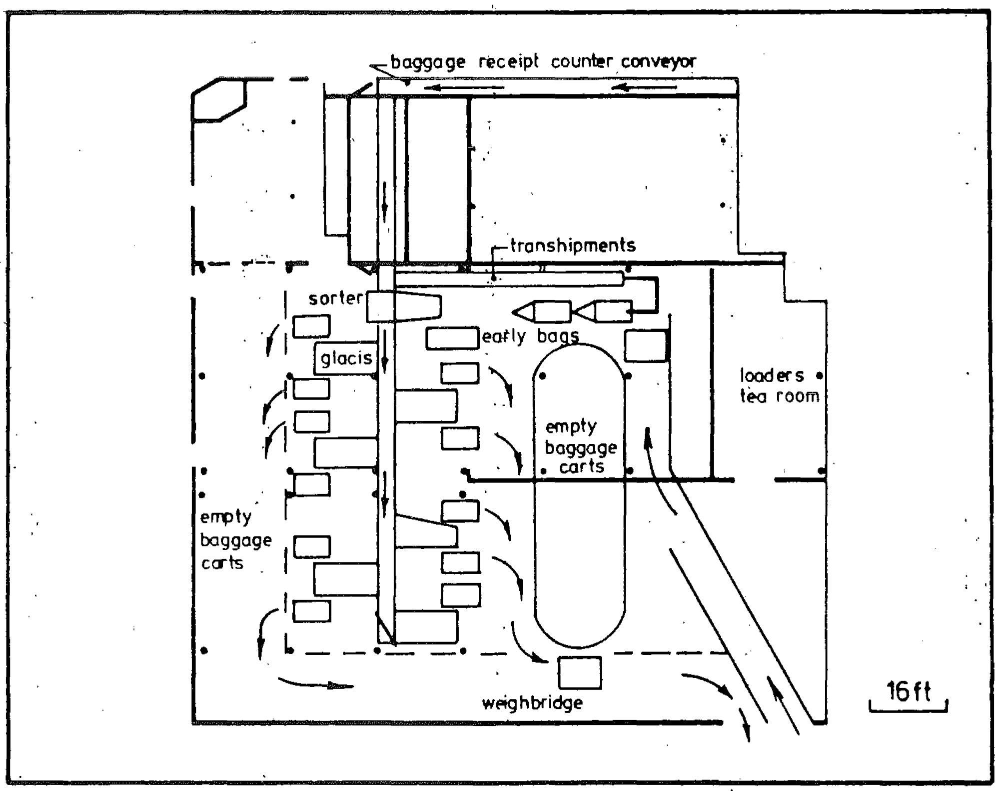


FIG. 10·5 BAGGAGE SORTING MACHINE PROPOSAL day plus a proportion of the foreman's time per shift. Secondly by increasing baggage cart size and providing a suitable tractor to tow them between their loading position and weighbridge, worthwhile labour savings could result.

An estimate of expected costs was prepared for each alternative, from which management could choose the most attractive for detailed investigation. The second proposal (2) was chosen and detailed equipment selections requested.

Given a specific class of handling equipment the designers task is to select a particular item to meet constraints of the baggage transfer, building space available, and subsequent handling activities. By intuition the designer chose four combinations of equipment which he believed to be capable of performing the material transfer between the check-in counter and baggage make-up.

(1) Figure 10.6 illustrates the first proposal. The check-in counter conveyor transfers all checked baggage onto a feeder conveyor which rises to allow access beneath the conveyor. The feeder conveyor then merges tangentially with a loop conveyor from which bags are identified and unloaded manually onto the appropriate baggage carts. Equipment required for this layout includes:

(a) Straight conveyors including eighty-five feet of new conveyor behind the check-in counter.

(b) Two right-angle conveyors.

(c) A loop conveyor.

(d) Loop conveyor side covers and fittings.

(e) Weighbridge printer.

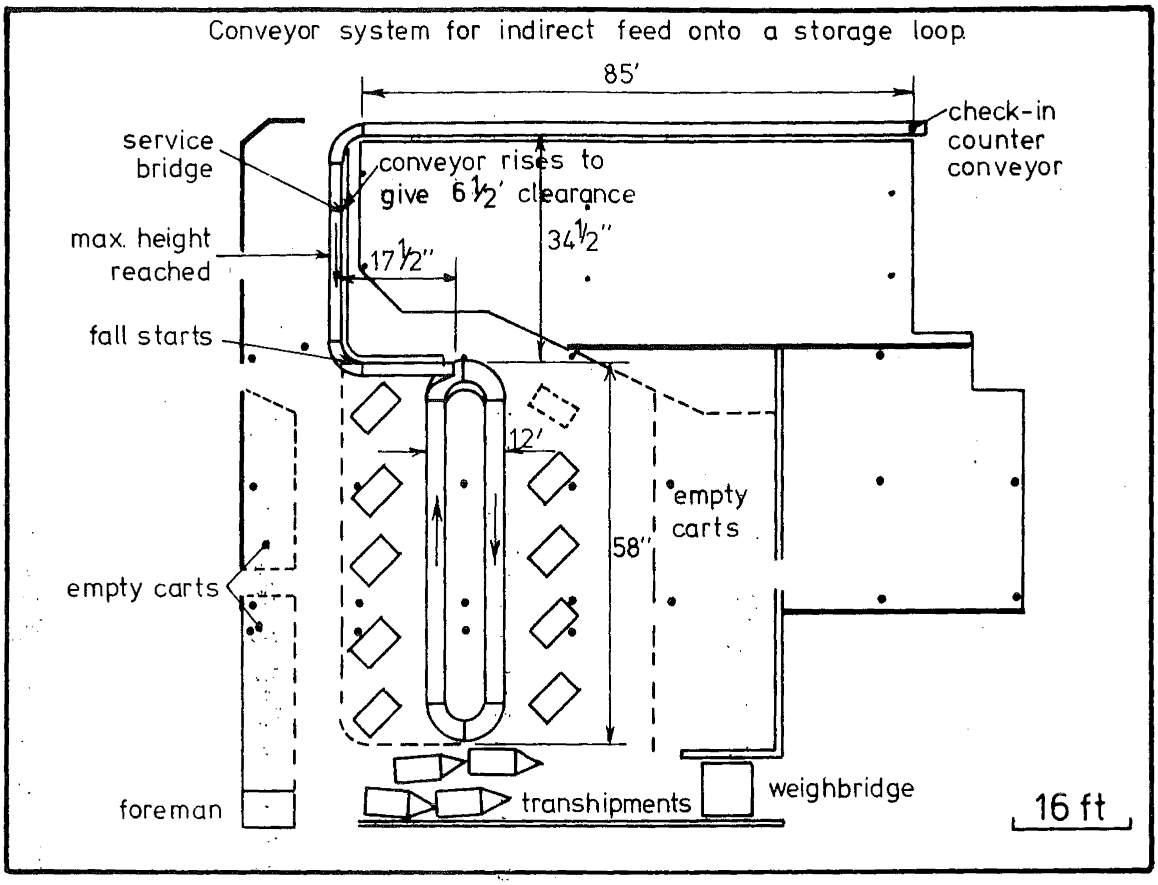


FIG. 10·6. PROPOSAL ONE

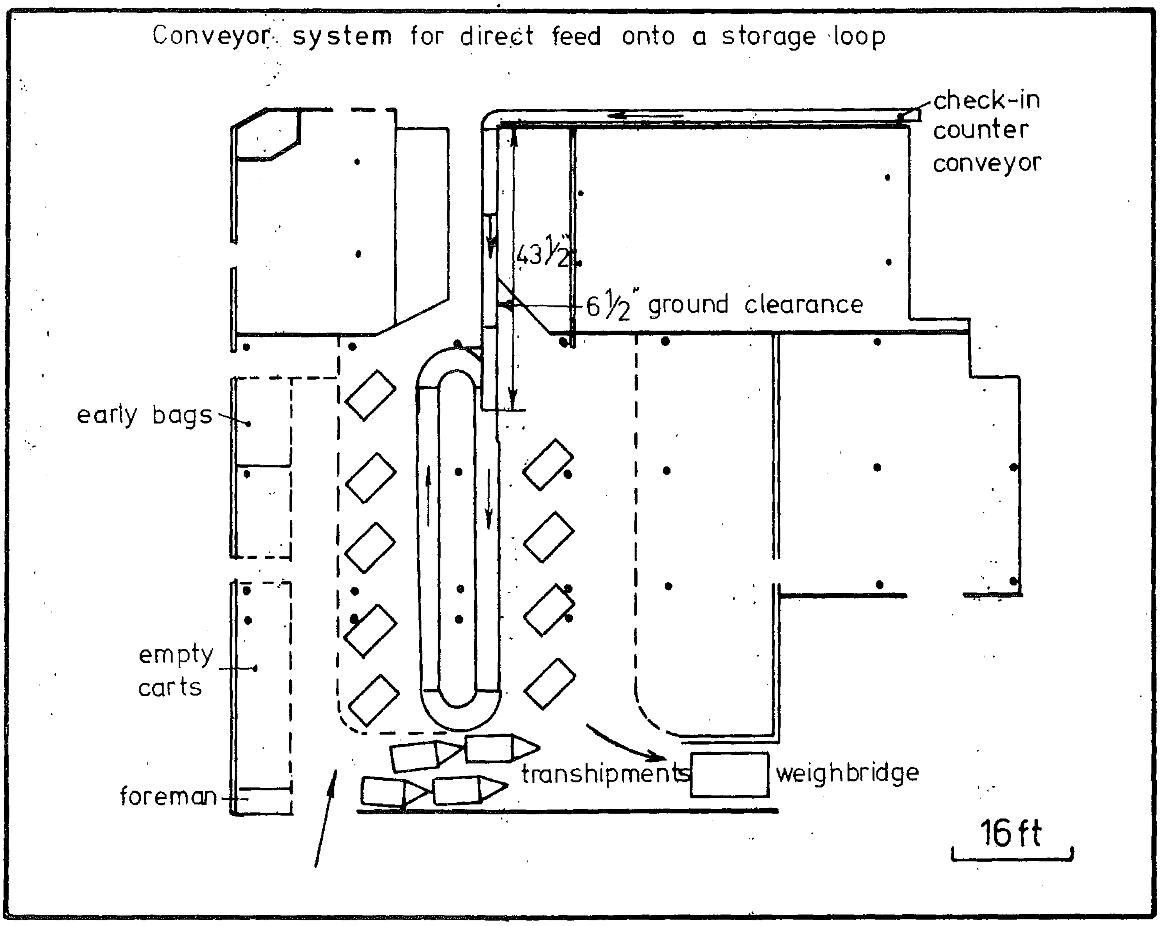


FIG. 10·7 PROPOSAL TWO

(2) The second proposal involves an alternative layout for the feeder conveyor as illustrated in Figure 10.7. Equipment selected for this layout includes:

(a) Straight conveyors including sixty-two feet of new conveyor behind the check-in counter.

(b) One right-angle conveyor.

(c) A loop conveyor.

(d) Loop conveyor side covers and fittings.

(e) Weighbridge printer.

(3) The third proposal includes a longer storage loop to give thirty per cent increase in storage capacity thereby reducing peak staff requirements and early bag storage capacity. Significant building alternatives are required to accommodate this proposal. More effort is required from the foreman to control the transhipment loading point and to ensure a smooth traffic flow. Figure 10.8 illustrates this layout. Equipment selected includes:

(a) Straight conveyors including sixty-two feet of new conveyor behind the check-in counter.

(b) One right-angle conveyor.

(c) Loop conveyor.

(d) Loop conveyor side covers and fittings.

(e) Weighbridge printer.

(4) Proposal four is illustrated in Figure 10.9. Although similar to proposal three it incorporates the shorter storage loop of proposals one and two, which reduces capital costs by approximately $5,000. Equipment required is the same as for proposal three excepting the shorter storage loop.

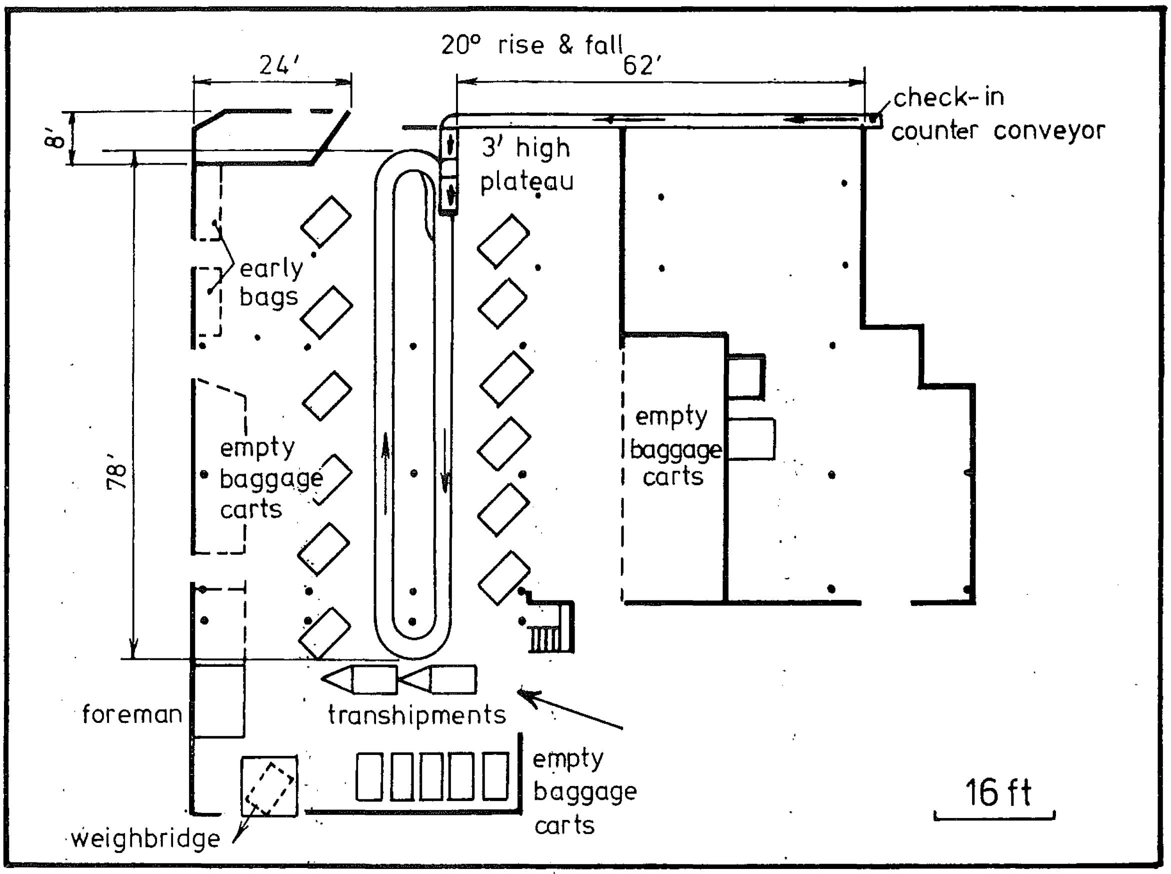


FIG. 10·8 PROPOSAL THREE

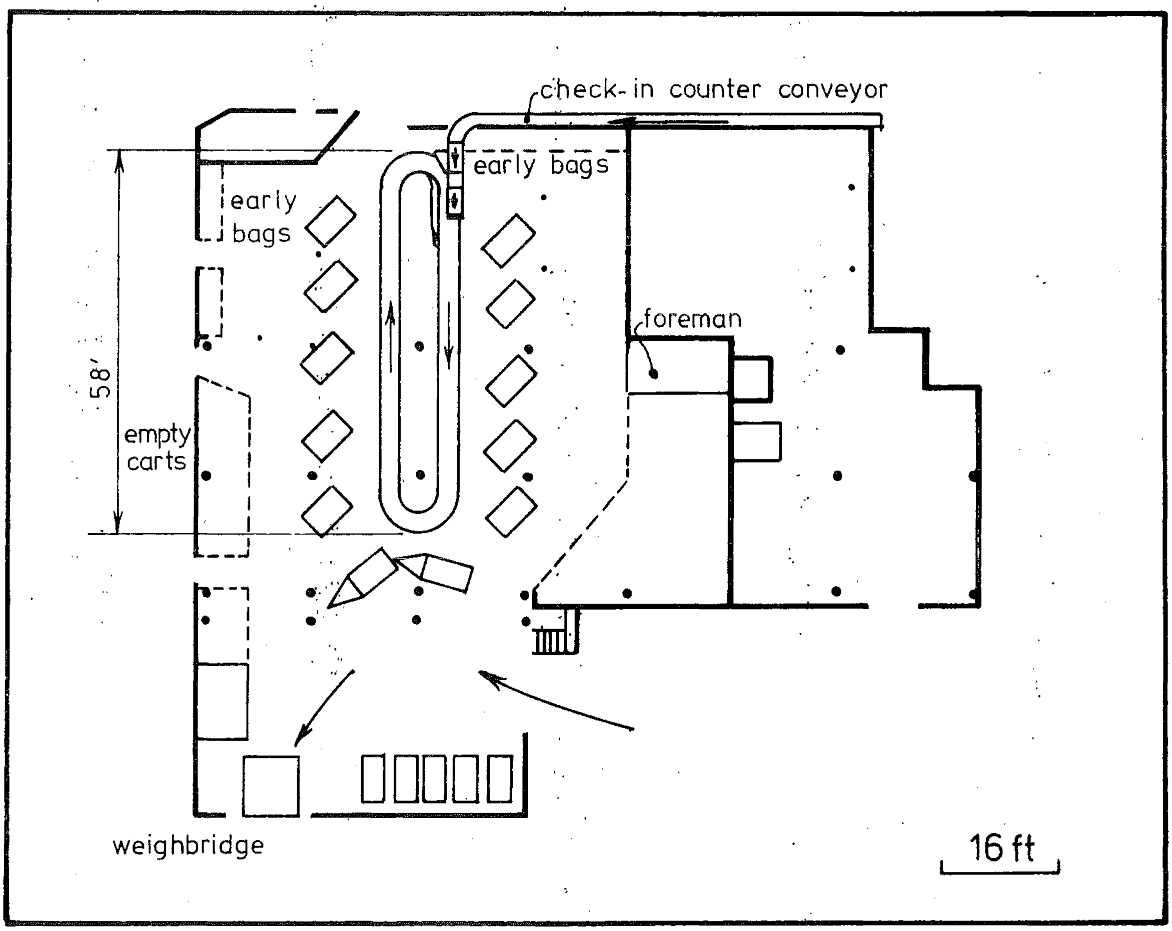


FIG. 10·9 PROPOSAL FOUR

Essential physical properties of each solution include:

(1) The width of each loop is chosen to be fourteen feet to allow sufficient belt width for two lanes of bags to match commerically available 180° bends.

(2) An operating speed of eighty ft/min. was chosen for the loop and eighty-five ft/min. for the feeder. At eighty ft/min. a bag loading rate of fourteen bags/min. and a belt centreline length of 126 feet, gives a storage time of 3.15 minutes per revolution at a bag spacing of 5.7 feet. The longer storage loop having a centreline length of 166 feet, storage time is increased to 4.2 minutes.

(3) The designers proposed that flat plastic trays be provided to contain irregularly shaped objects which do not convey easily. This eliminates need for hand transfers between the check-in counter and make-up area.

The designers believed they had considered all relevant technical details and so proceeded to evaluate each proposal by estimating capital cost of equipment required, and direct labour costs. No other costs were made explicit. Figure 10.10 illustrates expected weekly staff loadings for proposal three while Figure 10.11 tabulates equipment costs for each proposal. Based upon these costs, management chose proposal three for implementation.

10.3 The Design Procedure Illustrated.

The handling system design procedure developed in the previous chapter begins by requesting identification of essential handling activities. General functions of the baggage handling system are; (1) to accept and load passengers' bags into departing aircraft, and (2) to unload incoming aircraft and return bags to their owners. Consider the specific functions

Total hours worked per week	–	loaders	340
	–	foremen	123
Total cost per week	–	loaders	$ 957
	–	foremen	$ 425
Total cost per year	–	loaders	$ 49,000
	–	foremen	$ 22,000
			$ 71,000

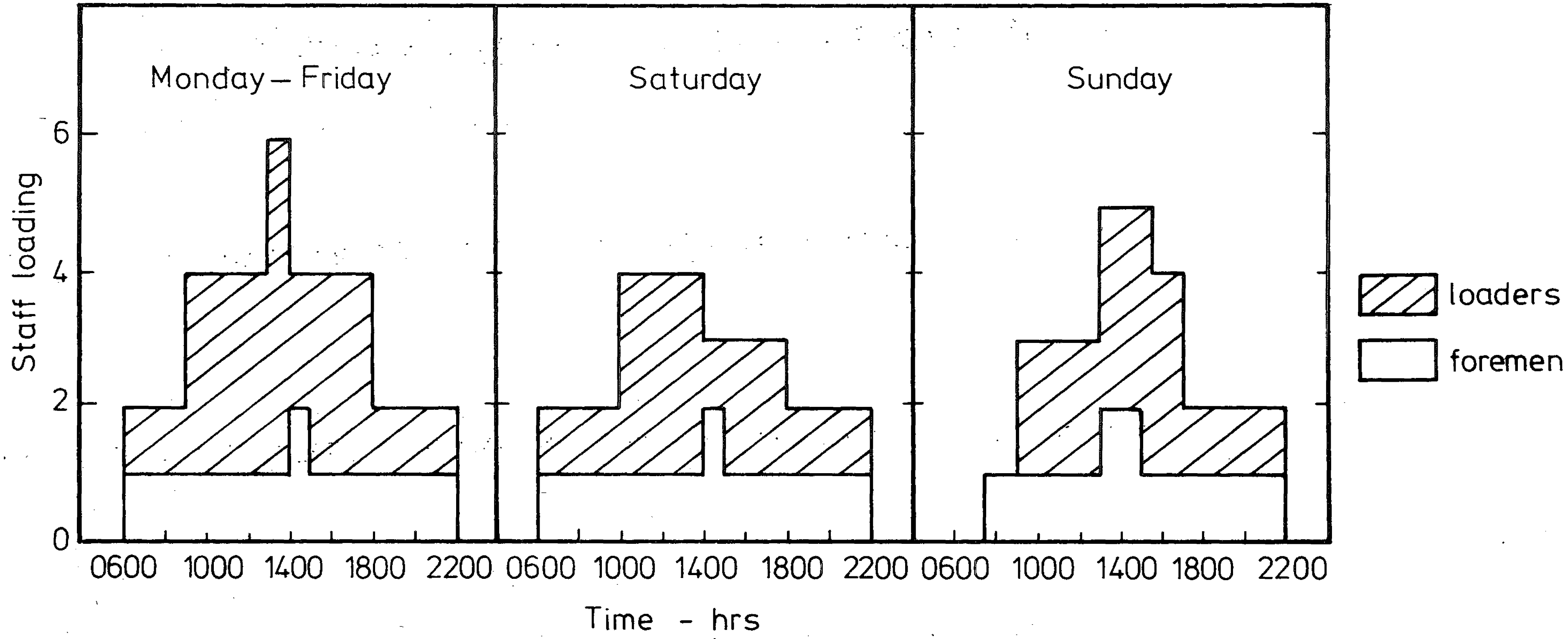


FIG. 10·10 LABOUR COSTS FOR PROPOSAL THREE.

Equipment \ Proposal	1	2	3	4
Straight Conveyors	$26,000	$21,000	$14,800	$14,800
Right-Angled Conveyors	$10,000	$5,000	$5,000	$5,000
Loop Conveyors	$35,000	$35,000	$40,000	$35,000
Fittings	$10,000	$10,000	$10,000	$10,000
Weighbridge Modifications	$6,000	$6,000	$6,000	$6,000
TOTALS	$87,000	$77,000	$75,800	$70,800

FIGURE 10.11 THE EQUIPMENT COSTS FOR EACH PROPOSED EQUIPMENT SECTION

necessary to achieve these general functions:

(1) Accepting bags requires that two functions be performed; (1) bags must be inspected to ensure they comply with legal requirements, and (b) bags must be identified to both the aircraft upon which they are to travel and their owner. Since baggage is accepted for several aircraft at any one time it is necessary to provide a sorting function capable of grouping baggage into loads designated to specific aircraft. The weight of these loads must be provided to the pilot prior to departure. Finally, bags must be transferred to the appropriate aircraft and loaded into baggage holds.

(2) Unloading incoming aircraft involves identification of transhipment baggage and destination baggage. Transhipment baggage is then returned to baggage make-up whilst destination baggage is taken to self-claim for removal by passengers. Provision must be made to secure any unclaimed baggage.

Given these specific functions related to the handling process, six handling activities are identified. These are illustrated in Figure 10.12.

For each handling activity general structural properties are identified:

Activity One - acceptance of baggage.

(1) The material: Size and contents of baggage is strictly controlled. For example, limits are placed upon dimensions allowed for "free" baggage, namely the sum of the linear dimensions must not exceed 1500 mm. Specific restrictions are placed upon contents such as compressed gases, corrosives, explosives, firearms, flammable liquids and solids, oxidising material, poisons, radioactive material, and so on.

(2) The transfer is between the public foyer in the terminal building and the check-in counter as illustrated in Figure 10.1.

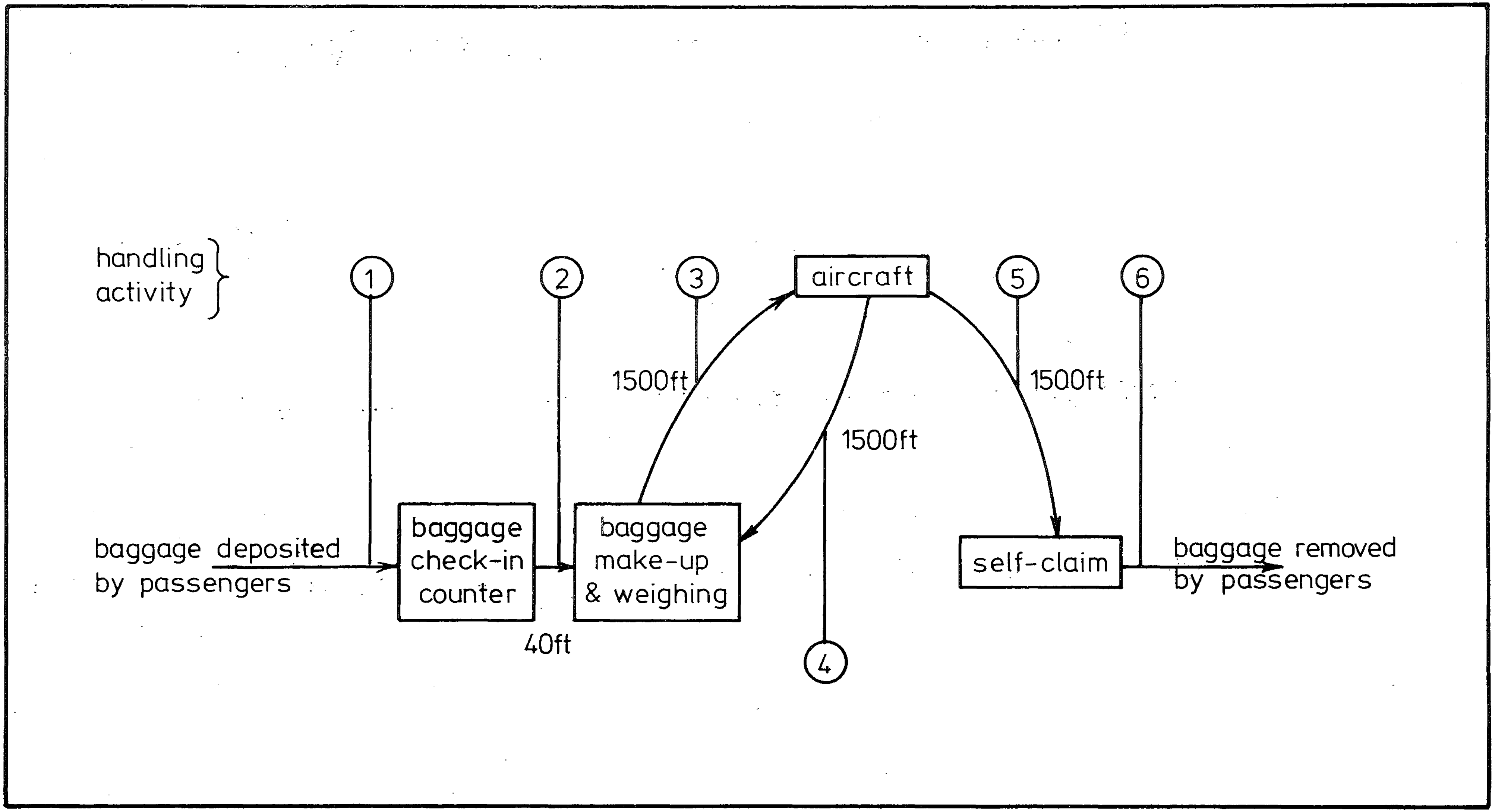


FIG 10·12 MATERIAL TRANSFERS IN THE BAGGAGE HANDLING SYSTEM.

(3) Rate of transfer is determined by the flight timetable and passenger demand within this timetable. The airline attempts to satisfy all demands within its capability, therefore the handling system must be designed to match peak passenger flows into, and from Wellington Airport. This peak produced an estimated baggage flow rate of ten bags per minute which was projected to increase to fourteen bags per minute within six years. The arrival distribution of bags for any aircraft is shown in Figure 10.13. Bags begin arriving about one hour before departure time, and continue to arrive at a steady rate until about two minutes before scheduled departure time. Within any one hour period up to ten flights may depart, therefore the check-in counter must be able to check bags for ten flights at fourteen bags per minute.

(4) To relieve peaks near departure time, passengers are requested to check-in bags at least fifteen minutes before departure.

Activity Two - Check-in counter to baggage make-up.

(1) Baggage remains physically unchanged.

(2) The transfer is between the check-in counter and the make-up area within the terminal building. Figure 10.1 illustrates the geometry of the transfer.

(3) Peak transfer rate is fourteen bags per minute.

(4) The principal constraint upon transfer is that the baggage identification tag must be clearly visible on arrival in the make-up area.

Activity Three - Baggage make-up to aircraft.

(1) Baggage remains physically unchanged.

(2) The gross length of transfer path is approximately 1500 feet but varies depending upon the parking position of aircraft within the aircraft park. The transfer is entirely on a horizontal surface.

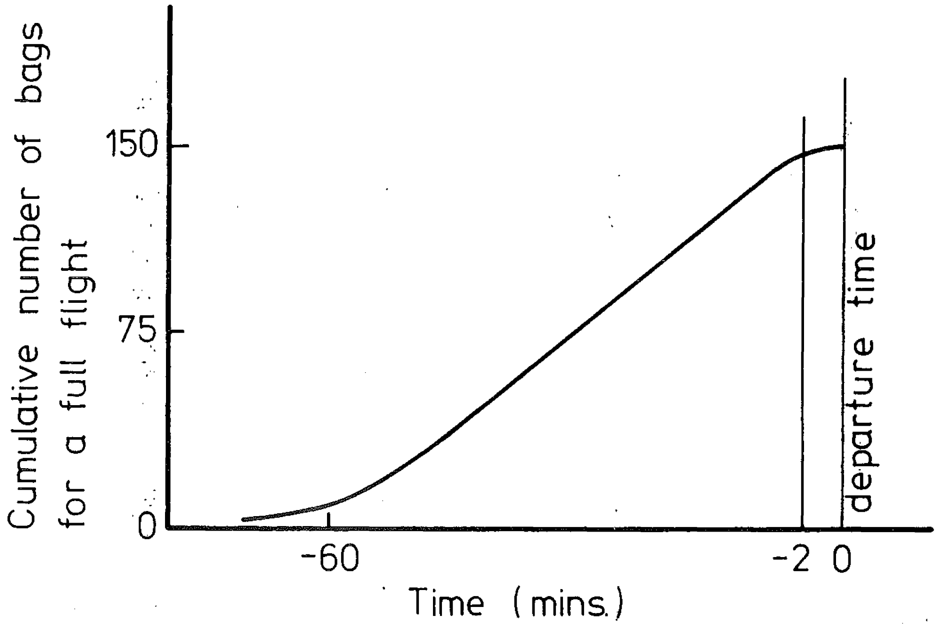


FIG. 10·13. THE ARRIVAL DISTRIBUTION OF BAGGAGE AT THE CHECK-IN COUNTER FOR ANY ONE FLIGHT.

(3) Turnaround time for an aircraft varies depending upon a number of factors but an acceptable minimum is twenty minutes. This time must be shared between activities three and four each of which take a similar time. Therefore approximately ten minutes are allowed to transfer a full load of 150 bags between baggage make-up and the aircraft hold. Most of the bags may be weighed before they leave baggage make-up. Over any one hour period up to ten aircraft may depart, therefore sufficient storage must be available to accumulate bags for ten separate flights, plus early bags arriving prior to one hour before departure.

(4) Timing of this activity is important because baggage must be ready for transfer as soon as the aircraft has been unloaded. Weighing activities must not average longer than six minutes per aircraft load.

<u>Activity Four</u> - Aircraft to baggage make-up for transhipments.

(1) Baggage remains physically unchanged.

(2) The gross length of transfer between aircraft and baggage make-up is approximately 1500 feet in a horizontal plane.

(3) Because Wellington Airport is a common intermediate destination, approximately thirty per cent of baggage on non-terminating flights is transhipment baggage. Therefore the peak transfer rate may be 150 bags within any fifteen minute period. Some of these bags may not need to be sorted for a period of an hour or more, therefore storage must be provided.

(4) This activity is performed as soon as an aircraft arrives in conjunction with transfer five.

<u>Activity Five</u> - Aircraft to self-claim.

(1) Baggage remains physically unchanged.

(2) The gross length of transfer is approximately 1500 feet in a horizontal plane between the aircraft and self-claim.

(3) A minimum of approximately ten minutes is allowed to unload transhipment, and destination baggage per aircraft, of which up to three may

arrive within a fifteen minute period. Provision must be made to store bags in the self-claim area at this rate since passengers require approximately 15 minutes to identify and remove their bags.

(4) Constraints include timing of the activity to meet an incoming aircraft, identification in self claim of the flight from which bags are removed, and the safety of passengers while they are identifying and unloading their bags.

<u>Activity Six</u>

(1) Baggage remains physically unchanged.

(2) The building area within which self-claim is to be sited is illustrated in Figure 10.2.

(3) A maximum service time of fifteen minutes is satisfactory for passengers to identify and remove their bags.

(4) A secure storage area must be provided for any unclaimed bags. Close proximity to both public and private transport is important.

Having identified the essential features of each handling activity, the design procedure asks for an examination of the necessity for each activity. No two activities can be combined, however three, four, and five, are similar and place similar demands upon handling equipment required.

The next major decision is concerned with determining the transfer mode of the material, that is either as a batch or continuously. Consider factors contributing to this decision for activities two, three, four, and five. Activities one and six do not require any equipment selection but they do constrain the other activities.

<u>Activity Two</u>

A steady rate of transfer with time, length of transfer path, and life of the activity, all favour a continuous transfer mode.

Activities Three, Four, and Five

Rate of transfer varies in discrete steps with time. Whenever an aircraft is loaded or unloaded, the load must be transferred in an interval of approximately ten minutes. This combined with variability of the transfer path shape within the baggage make-up area and aircraft park indicates a batch transfer mode.

Having identified the essential features of each transfer, as well as making a tentative decision on a batch or continuous transfer mode, the next stage involves identifying constraints imposed upon each transfer by the environment. Consider relevant constraints for each transfer.

(1) Geometry of the terminal building constrains all six transfers. Some flexibility is allowed by moving internal partition walls, but structural columns illustrated in Figure 10.1 cannot be altered. The aircraft park is organised by flight operations who position aircraft as they arrive. Equipment chosen must be able to operate within this positional variation. Geometry of building space available for self-claim constrains activities five and six.

(2) Two operations must be performed within the handling process which determine and constrain handling activities; (1) baggage must be identified and inspected to ensure it complies with the law, and (2) each load of baggage must be weighed. These operations limit time available to perform handling activities two and three. Because baggage inspection and identification requires a human operator, special constraints and determinants must be considered such as physical work limits, hours of work, comfort, safety, and union award agreements must be considered. Baggage should be weighed as quickly as possible to allow loaders maximum time at the aircraft.

(3) During activities three, four, and five, baggage will be exposed to the weather; this is unacceptable and protection must be provided.

Organisational constraints include:

(1) Management stated the design criterion as minimising costs within the functional requirements of the system. Timing of the project was set at one year from the initial decision to examine existing handling methods.

(2) Design work would be performed by experienced industrial engineers within the organisation.

(3) Any solution must consider status of existing loading staff and foremen whose jobs may be changed or eliminated.

(4) Maintenance expertise existing within the organisation is sufficient to maintain a wide range of handling equipment.

Six handling activities have been identified together with major constraints upon equipment selected, and upon the designer himself. His task now is to choose general structural classes of handling equipment capable of performing each activity within identified constraints. Consider how properties of the handling activities identified aid designers to select equipment.

Activity Two

Desirability of a continuous transfer mode, short length and fixed position of the transfer path, a six year working life, and size, shape, and weight of baggage all suggest conveyors as a feasible class of equipment.

Activity Three

A discrete transfer mode, variablity of position of termini of transfer path, length and shape of each transfer path, necessity to weigh each aircraft load, and variation in numbers of bags per load all suggest a self-propelled wheeled vehicle.

Activity Four

This activity possesses the same essential properties as activity three with exception of the weighing operation. A towed train of wheeled vehicles provides a logical choice.

Activity Five

Essential properties the same as activity four with the additional constraint that passengers must be able to claim their bags quickly and safely from the handling equipment. Again a towed train of baggage carts make a logical choice.

Conveyors and wheeled vehicles possessing the capacities required are available over a range of prices and within delivery times acceptable to management.

Given these tentative selections the next stage of the design procedure involves identifying compatibility relations between components of the handling situation and equipment chosen.

Activity Two

(1) Equipment - Material

(a) Linear dimensions of baggage determine conveyor belt width.

(b) Sides must be fitted to the conveyor to prevent bags falling at bends.

(c) Irregularly shaped objects must be placed upon trays to ensure they convey satisfactorily.

(d) Conveyor surface must be smooth and continuously supported to prevent damage to bags.

(2) Equipment - Environment

(a) Sufficient space is available within the existing building to contain a conveyor system. The most acceptable transfer route is the most direct route which minimises conveyor length and bends.

(b) Access must be provided around the conveyor along its length.

(c) Conveyor must generate minimum noise.

(d) Each bag must be approved for acceptability. Although the criteria are clearly defined the high variety in the inspection task indicates a need for a human inspector.

(3) Equipment - Equipment:

(a) Because baggage is transferred continuously in activity two and discretely in activity three, provision must be made to store bags. Variations in the tasks of recognising baggage destination and placing them on equipment performing activity three suggests a human loader is required.

(b) Handling activity four is a batch transfer which must be compatible with transfer two. Temporary storage is needed together with recognition and manipulative skills to place bags onto the conveyor. Human operators make a logical choice.

Activities Three, Four, and Five.

(1) Equipment - Material:

(a) Range in size and weight of baggage combined with variation in number of items per aircraft load, constrains vehicle carrying capacity.

(b) Bags must be securely contained to prevent damage during transfer.

(2) Equipment - Environment

(a) Vehicles must be able to manoeuvre within baggage make-up and self claim areas, travel through existing doorways, and approach the aircraft baggage hold.

(b) Timing of activities three, four, and five are determined by arrival and departure times of aircraft. The foreman's task is to coordinate each activity.

(c) During each transfer, baggage must be protected from the weather. Also these activities must be performed during all weathers.

(d) Human loaders must be provided with protection enabling them to work in all weather.

(3) <u>Equipment - Equipment</u>

(a) Unloading actions of activity four must not interfere with loading actions of activity three.

(b) Baggage must be clearly identified between activities four and five.

(c) Storage requirements between activities five and six will require provision of a secure store administered by a staff member for any unclaimed baggage.

Satisfying these compatibility relationships has the effect of reducing the number of feasible solutions within the general equipment classes already chosen. For example, belt conveyors were chosen as a general class of equipment for transfer two. Compatibility relations impose the following constraints:

(1) The conveyor channel cross-section is constrained by baggage dimensions, and commercially available conveyors. Figure 10.14 illustrates a suitable example.

(2) Storage requirements, geometry of the building, size and weight of bags, staff numbers, and availability of equipment, determine the physical dimensions of the conveyor loop. The cross-section of a suitable conveyor loop is illustrated in Figure 10.15.

(3) Feasible layouts within available building space is illustrated by solutions presented in the preceding section, (Figures 10.6 - 10.9).

(4) Compatibility between equipment chosen for transfers two and three indicate that; (1) a storage operation is necessary, and (2) baggage identification and placement require the manipulative skill of a person.

FIG. 10·14 CROSS SECTION OF FEEDER CONVEYOR

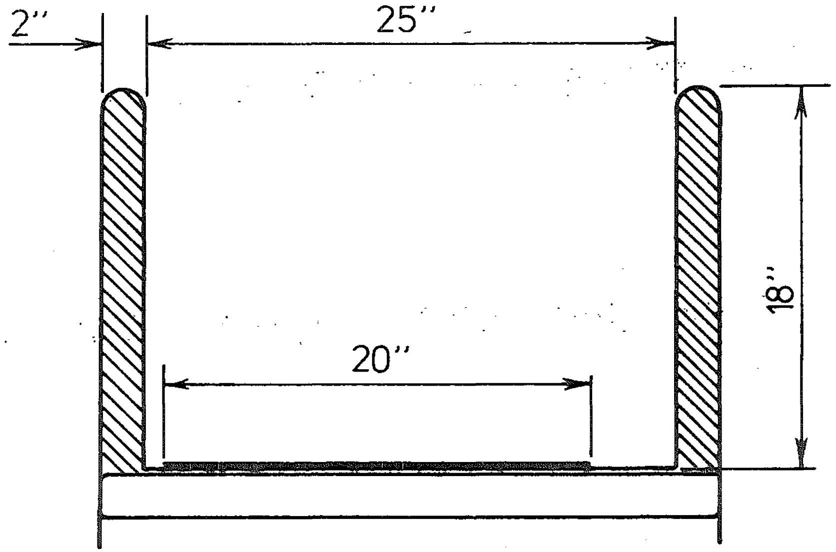
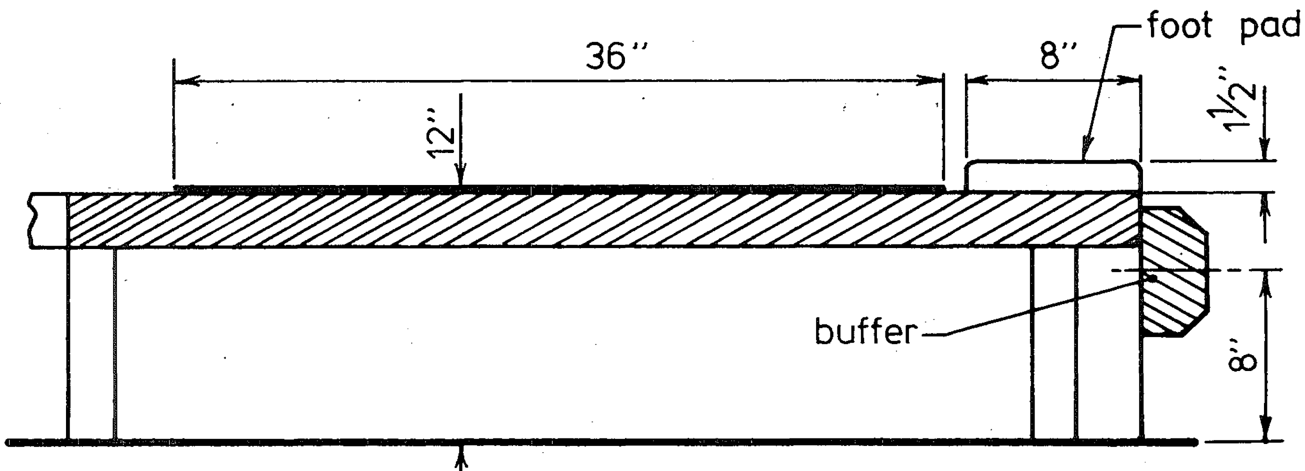


FIG. 10·15 CROSS SECTION OF ONE HALF OF STORAGE LOOP CONVEYOR



Satisfying compatibility relations between handling activites reduces possible combinations of handling equipment and involves selecting additional equipment.

The next stage in the design procedure examines the need for packaging. Neither the physical properties of the baggage, proposed handling equipment, nor physical properties of the environment indicate a need for packaging.

Effects of equipment chosen upon the organisation are examined next.

(1) The management structure will not alter as a result of the proposed solution. However, resources such as finance to design, purchase, and install technically feasible solutions must be allocated by management. The operating budget must also be approved by management.

(2) The proposed system will not require any changes in the capacity of baggage inspection and identification, nor in the weighing activity. Insofar as the weighing activity is a bottleneck to handling, it may be desirable to increase its capacity.

(3) Existing maintenance activities will be able to maintain proposed equipment without additional resources.

(4) Existing design experience is sufficient to produce a satisfactory design.

(5) The existing handling system is regulated by a foreman who is informed of aircraft arrival and departure times, and coordinates men and equipment for each activity. The proposed system will not require additional regulating actions.

The designer has now identified all technical and organisational factors influencing selection of handling equipment. The next stage in the design procedure involves identifying suitable achievement measures for each feasible alternative.

As an illustration of costs involved to distinguish between feasible alternatives, consider some estimates made for feasible alternatives chosen for activity two. These are illustrated in Figure 10.16. Based upon initial capital costs plus expected operating costs over a period of six years, proposal three was taken as optimum.

Monitoring system performance under changing conditions such as changes in baggage handling rates, type of aircraft used, policy on "free baggage allowance", and so on, requires identification of suitable measures. Consider such measures for transfer two.

(1) Actuality - measures of actual output include:

(a) Rate of baggage transfer for different time intervals, say, minutes, hours, days, and years.

(b) Energy requirements per unit time.

(c) Labour requirements per unit time.

(d) Maintenance requirements and costs per unit time or item of equipment.

Often it is convenient to express each of these measures in terms of a cost dimension such as cost of energy per unit time, and so on.

(2) Capability - the capability of socio-technical systems are limited by the capacity of their components. For example in transfer two, individual components include:

(1) Inspector/loaders at the check-in counter.

(2) Check-in counter conveyor.

(3) Storage loop conveyor.

(4) Loaders transferring baggage from the storage loop onto baggage carts.

	Proposal 1	Proposal 2	Proposal 3	Proposal 4
Capital Cost of Equipment	$81,000	$71,000	$69,800	$64,800
Installation and Commissioning Costs	$15,000	$12,000	$18,000	$16,000
Energy Costs/Year	$1,000	$1,000	$1,000	$1,000
Labour Costs/Year	$96,000	$77,000	$71,000	$77,000
Expected Maintenance Costs/Year	<$1,000	<$1,000	<$1,000	<$1,000
Expected Design Costs	$5,000	$5,000	$5,000	$5,000

FIGURE 10.16 EXPECTED COSTS FOR EACH PROPOSED ALTERNATIVE

For the present system it has been found that over a period of fifteen minutes each inspector/loader checks up to four bags per minute. This is his capability. Up to three inspectors may be employed concurrently. The check-in counter conveyor possessed a capability considerably in excess of that required; being able to transfer up to twenty bags per minute. Loaders could identify and place approximately two bags per minute in addition to performing the weighing operation. Up to six loaders are needed for peak flows thus their combined capability is twelve bags per minute. Thus the capability of the system is limited to twelve bags per minute; the capability of inspectors and baggage cart loaders.

(3) Potentiality - measures are required to indicate areas of potential improvement in components of the system. For example in transfer two a magnetic card identification system could decrease time spent identifying baggage at the check-in counter and also time spent by loaders matching bags to each baggage cart. A realistic potential transfer rate is five bags per minute per person at check-in and twelve bags per minute per person at the baggage carts.

With the selection of an optimum solution as exemplified for transfer two, and identification of performance measures as illustrated, the designer's task is complete. He has provided a detailed structural specification of suitable items of handling equipment.

10.4 A Comparison Between Formal and Intuitive Design Procedures

Two objections were raised against intuitive design procedures; (1) aprioristic assumptions used to choose handling equipment may constrain subsequent decisions to the detriment of the final design, (2) many of the relevant variables and constraints are implicitly identified which may lead to design errors. Any errors are usually discovered during implementation when ad hoc modifications are made to produce a feasible handling system. Such a procedure rarely leads to an optimal solution.

This section selects some examples of aprioristic assumptions and implicit identification of design variables from Section 10.2 to illustrate how errors may arise in the final design.

The human designers did not attempt to identify the essential functions which had to be performed by the handling system, and as such did not identify all six essential handling activities. They isolated two activities which they believed to be the cause of present system inefficiencies, these were, transfer between the check-in counter and baggage make-up, and the layout within self-claim. Current methods for inspecting, identifying, making up loads of bags, weighing, and transferring bags to and from aircraft were taken to be satisfactory. Each of these activities constrains solutions that the designers proposed and since they were implicitly accepted, any subsequent design decisions were constrained by them. For example, by accepting the present method for identifying bags implies that human loaders are to be used to load baggage carts in the make-up area. Such an assumption restricts improvement in capability of the system beyond that possible with human loaders. The formal design procedure recognised baggage identification as an essential activity and accepted one possible method of solution. If this method had proved too restrictive during subsequent stages of the design procedure, then alternatives could be considered because the activity and its effect upon the system had been made explicit. Similarly the assumption that the weighing activity had to be performed upon completion of baggage make-up was implicitly accepted whereas a superior solution may have been to identify and weigh bags during check-in. Again this assumption constrains alternatives available to the designer and should be made explicit.

The assumption that human loaders were necessary to unload the conveyor in baggage make-up constrains the designers' choice of conveyor and also methods for transferring bags to the aircraft.

Self-Claim was examined because customer complaints indicated the service provided was inadequate.

The designers did not identify or make explicit adequate measures for selecting either an optimal solution or for assessing performance of any chosen system. Management were required to choose between feasible alternatives using inadequate performance measures. Whether the new system was an improvement on the existing system was not established.

Finally, the influence of the proposed systems upon the organisation was not considered.

The formal handling system design procedure developed in Chapter Nine attempts to identify and make explicit classes of relevant variables necessary to produce a handling system design. A logical approach ensures assumptions made in assigning values to variables are made explicit, therefore the designer is aware of the influence of his assumptions upon each design decision. Such an approach reduces the possiblity of errors arising during the design procedure.

CONCLUSION TO PART TWO

The objective of Part Two was to develop a logical procedure for designing material handling systems and to demonstrate how this procedure is used to produce a design.

Nine design activities were identified which were believed to be both necessary and sufficient for designing a material handling system. Because they interact with each other during the design process they were considered as components of a design system. Interactions between these components were identified and the function of each within the design system examined.

Part One identified a design strategy comprising four stages:

(1) Identification of general functions of the handling system.

(2) Identification of specific functions to be performed by the handling system.

(3) Identification of general structural classes necessary to perform these functions.

(4) Identification of specific structural properties of items of equipment which are capable of performing these functions.

This general strategy combined with essential properties of a material handling situation was used to arrange the design components into a logical sequence. Such a sequence represents a logical design procedure which can be used to examine an industrial handling situation and select combinations of equipment capable of performing the handling activities.

Within this design procedure it is not clear which components can be performed by computer and which require human designers. Conditions necessary for computers to provide design assistance were discussed for each component of the design system.

Having developed a design procedure the next task was to ensure that it was able to produce designs under realistic conditions. To this end an actual handling system design problem was found and the design procedure applied to it. This example illustrated both, how the design procedure is to be used, and, that it is capable of identifying all relevent variables necessary to produce a satisfactory design. Furthermore these variables were examined in a logical order which made explicit each design decision as well as assumptions upon which each was based.

Finally, for this example, the logical design procedure was compared with the procedure used by human designers which demonstrated where the human designers had failed to consider several relevant aspects of the design, thereby increasing the probability of producing design errors.

CHAPTER ELEVEN

GENERAL CONCLUSIONS

The objective of this chapter is to provide a summary and conclusion to the work performed in this project, thereby providing a concise description of the essential facts.

The objective of the research performed in this project was to investigate applications of digital computers to aid the design of material handling systems. Since this is the first Ph.D. thesis to investigate this topic at the University of Canterbury, it was felt necessary to present the factors initiating this research. The need to increase the contribution of manufacturing industry to the New Zealand economy through improved technology warranted a brief discussion on the historical background to development of manufacturing industry. Philosophically our research group at the University of Canterbury believe that digital computers can perform a worthwhile role in industry by increasing productivity of technically qualified staff.

Having specified the objective of the research and identified the initiating factors the work was divided into two parts.

Part One was concerned with identification and definition of factors relevant to obtaining the project objective. Four principal factors were identified; (1) structural properties of handling situations which influence a designer's choice, (2) problems encountered in designing systems in general and handling systems in particular, (3) mental attributes possessed by human designers which enable them to produce designs, (4) characteristics of design problems which make computer solutions possible.

Part Two uses definitions and information developed in Part One together with design priciples and rules from current design literature, to develop a logical handling system design procedure. Application of this procedure is demonstrated and tested with an actual handling system design problem.

Consider results and conclusions of each part in more detail.

Principal results of Part One include the following:

(1) A handling activity is defined as a sequence of actions which produce a change in location and/or orientation of an object or quantity of material in space and time. Thus a logical analysis of existing material handling systems indicated four principal factors which interact; (1) a quantity of material or object to be handled, (2) a transfer path, (3) handling equipment, and (4) an environment within which the handling activities are performed.

Designing a handling system therefore involves producing a message describing essential features of the handling system such as handling equipment, regulating procedures, maintenance requirements, and so on, so that it can be produced. Producing a design requires an iterative procedure, creating, evaluating, creating, evaluating, and so on, until a satisfactory solution is reached. The sequence in which relevant variables are examined and decisions made is important.

To be consistent with our philosophy on problem solving a general strategy was proposed for performing the design process which includes four stages; (1) Identification of general functions of the handling system, (2) Identification of specific functions to be performed by the handling system, (3) Identification of general structural classes necessary to perform these functions, (4) Identification of specific structural properties of items of equipment capable of performing these functions.

Human designers are able to design handling systems and an examination of mental attributes which enable them to produce designs indicate that they visualise models of design situations. The human designer generates his model using perception, consciousness, and memory, and manipulates it with intuition and thought. Thought processes are conscious inferential processes whilst intuitive processes are unconscious. Apparently the creative aspects of designing require a combination of thought and intuition.

Evaluating the result of a creative process may be performed objectively or subjectively. Objective evaluation is on a clearly defined and measurable basis whilst subjective evaluation depends upon a person's feelings or on his untested beliefs. Four headings were proposed under which evaluations may be made; (1) on a scientific basis within established truths or technical constraints, (2) on an economic/political basis, (3) on a moral/legal basis, or (4) on an aesthetic basis.

Based upon this understanding of design processes, four automated design processes were examined. In each case it was found that:

(a) In the creative phase the program was supplied with a memory of a finite range of acceptable components which it could assemble as proposed solutions according to given rules, that is, according to a logical choice process. Designers had previously proposed these solutions intuitively. Researchers have found the discovery of a logical process to replace designers' intuition a major task.

(b) Proposed solutions of the creative phase were evaluated on a technical/scientific basis by procedures and criteria built into the program and ordered on an economic basis according to a clearly defined and agreed procedure.

Hence, as expected, although logical sequences were used which accomplished the same result as the intuitive process, none of these cases involved intuitive processes or subjective assessments.

If a computer is to be used to aid in designing a class of material handling systems, four criteria must be satisfied:

(a) A class of problems must be able to be described by a closed-set of measurable properties.

(b) A class of possible solutions must be able to be described by a closed-set of measurable properties.

(c) A set of relationships must be identified to match a solution to a given problem, and then ordered in a logical sequence.

(d) The person developing the computer program must possess or gain adequate knowledge or understanding of essential variables and relationships involved in the design process. An exhaustive search for possible relationships between essential properties is unlikely to yield a design method.

All the foregoing factors provide a basis for development of a logical procedure for designing material handling systems performed in Part Two.

Conclusions to Part Two may be summarised as follows:

(1) Designing a handling system appears to involve nine distinct design activities.

(a) Identification of the handling activities. This involves identifying the general functions of the handling system, that is the handling processes, which it must perform. Each handling process comprises a sequence of handling activities which must be defined.

(b) Collection of data. This involves examining the material and transfer path to specify essential structural properties.

(c) Determination of relevant data. Criteria must be specified to determine what properties are relevant to define the handling situation.

(d) Suggesting classes of equipment which appear to be satisfactory. Based upon collected data the designer must suggest possible classes of equipment that he believes can perform the handling activities.

(e) Suggesting further limitations based upon design experience, principles of material handling, and so on.

(f) Selection of feasible handling systems. Individual items of handling equipment are chosen from general classes using constraints identified in (e).

(g) Evaluation of performance of feasible alternatives.

(h) Assigning performance measures to feasible alternatives, ordering them according to performance criteria.

(i) Recycle design procedure if no solution is sufficiently satisfactory.

The sequence in which these activities should be performed is not however obvious, as they are interrelated during the design process. Combining the general design strategy proposed in Part One produced a logical design procedure. This procedure is illustrated in Figure 9.7.

(2) To prove that the design procedure is capable of identifying correct classes of variables and processing them in a logical and practical manner, an actual handling system design problem was solved. This example illustrated how the design procedure is used and that it is able to produce solutions logically. When compared with an intuitive approach taken by human designers, deficiencies were discovered in the intuitive approach which could lead to design errors.

(3) Assistance provided by a computer in this logical procedure when applied to a class of handling system design problems depends ultimately upon economic factors. These include cost of research effort necessary to

identify closed sets of relevant properties and their relationships, cost of preparing the computer program, and cost of producing a design using the computer. Such research, development, and operating costs must be less than current design costs including cost of design time, probable cost of producing suboptimal solutions, and cost from increased probability of design errors, if a computer is to prove an economic alternative. Generally, wherever a class of design problems are performed on a regular basis and time required for a human designer is significant, the possibility of computer aid should be examined.

(4) Although a general design procedure has been developed, it is anticipated that it will be used as a skeletal procedure for designing specific classes of handling systems in conjunction with digital computers. Classes of problems already exist within New Zealand such as designing handling systems within the logging industry, and for selecting industrial robots in manufacturing and processing industries. A project is anticipated within the near future which will examine applications of robots to industrial handling activities. The design procedure developed in this project will be applied.

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